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Agricultural producers need improved approaches to nitrogen management to reduce the risk of nitrate contamination of surface and groundwaters. Dairies produce large quantities of manure which can be used as a fertilizer, become a source of pollution, or both, depending on management. Many dairies in the Willamette Valley grow silage corn (*Zea mays* L.) for feed. To improve nitrogen management efficiency, growers need methods for evaluating corn crop nitrogen status. This study examined several soil and plant analyses as potential components of a nitrogen monitoring program for silage corn.

Twenty-six 26 experiments were performed on 17 farms. Two predictive tests, soil nitrate at planting (SNAP) and the Pre-sidedress Soil Nitrate Test (PSNT), and two evaluative tests, corn stalk nitrate at harvest and residual soil nitrate, were calibrated. Sites were identified as N-responsive if yield from unfertilized plots was less than 94% of yield from plots recieving 200 kg N ha^{-1} sidedressed at the V5 or V6 growth stage.

The PSNT correctly identified 88% of the sites as having either sufficient or insufficient N for maximum yield. When PSNT concentrations were above 21 mg

NO_3-N kg^{-1} soil, additional N was unlikely to improve yields. Twenty-two of 26 sites tested above the critical value. A SNAP value of 22 mg NO_3-N kg^{-1} soil or above indicated N was sufficient for maximum yield. SNAP values below 22 mg NO_3-N kg^{-1} did not necessarily indicate N deficiency, and the SNAP needed to be followed by a PSNT to determine N status.

Corn stalk nitrate concentrations at harvest were useful for identifying sites where insufficient, adequate, or excessive N had been supplied to the crop. A critical range of 3500-5500 mg NO_3-N kg^{-1} indicated an adequate N supply during the growing season. Residual soil nitrate concentrations above 16 mg NO_3-N kg^{-1} in the surface 30 cm (65 kg NO_3-N ha^{-1}) indicated N had been supplied in excess of crop demand.

The small number of N-responsive sites in this study suggests N from manure can replace most or all of the nitrogen fertilizer presently applied to silage corn on many Willamette Valley dairies.

Evaluation of Soil and Plant Analyses as Components of a Nitrogen Monitoring Program for Silage Corn

by

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Ernest S. Marx

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INTRODUCTION

Public concern regarding nitrate (NO_3^-) contamination of ground and surface waters is increasing. Agriculture is often cited as a source of nitrates. Dairies, with large volumes of manure, are among those operations receiving the most scrutiny.

Many dairies in western Oregon grow corn (*Zea mays* L.) for silage. Commercial nitrogen fertilizers are often applied to the corn crop either at planting, at the V5 growth stage, or both. Dairy manure is also applied to corn fields, though the fertilizer value of manure is often not considered. As a result, nitrogen is often supplied in excess of crop uptake, creating the potential for leaching of residual soil nitrate.

To improve nitrogen management, producers need methods for monitoring crop nitrogen status to determine fertilizer needs. Making accurate nitrogen fertilizer recommendations for corn based on preplant soil nitrogen levels has met with limited success, especially in humid regions. The difficulty in predicting the biological process of nitrogen mineralization is a primary obstacle in predicting the nitrogen supplying capability (NSC) of a soil. NSC predictions are especially difficult in agricultural systems with large inputs of organic matter, such as manure, since the organic matter constitutes a large pool of potentially mineralizable nitrogen.

An alternative to preplant soil testing was developed in Vermont by Magdoff et al. (1984). Magdoff's method, termed the pre-sidedress soil nitrate test (PSNT), is to delay nitrogen fertilization and measure the soil nitrate-nitrogen (NO_3-N) concentration when corn is at the V5 growth stage (Fig. 1). By delaying soil testing as long as possible, an *in situ* assessment of nitrogen mineralization can be made. The V5 growth stage is just before the corn plant's period of rapid N uptake. Also, the corn plant height at the V5 stage is approximately 30 cm, which is the limit of the grower's practical ability to make a sidedress fertilizer application. The PSNT method has been used successfully in many northeastern, mid-Atlantic, and mid-western states.

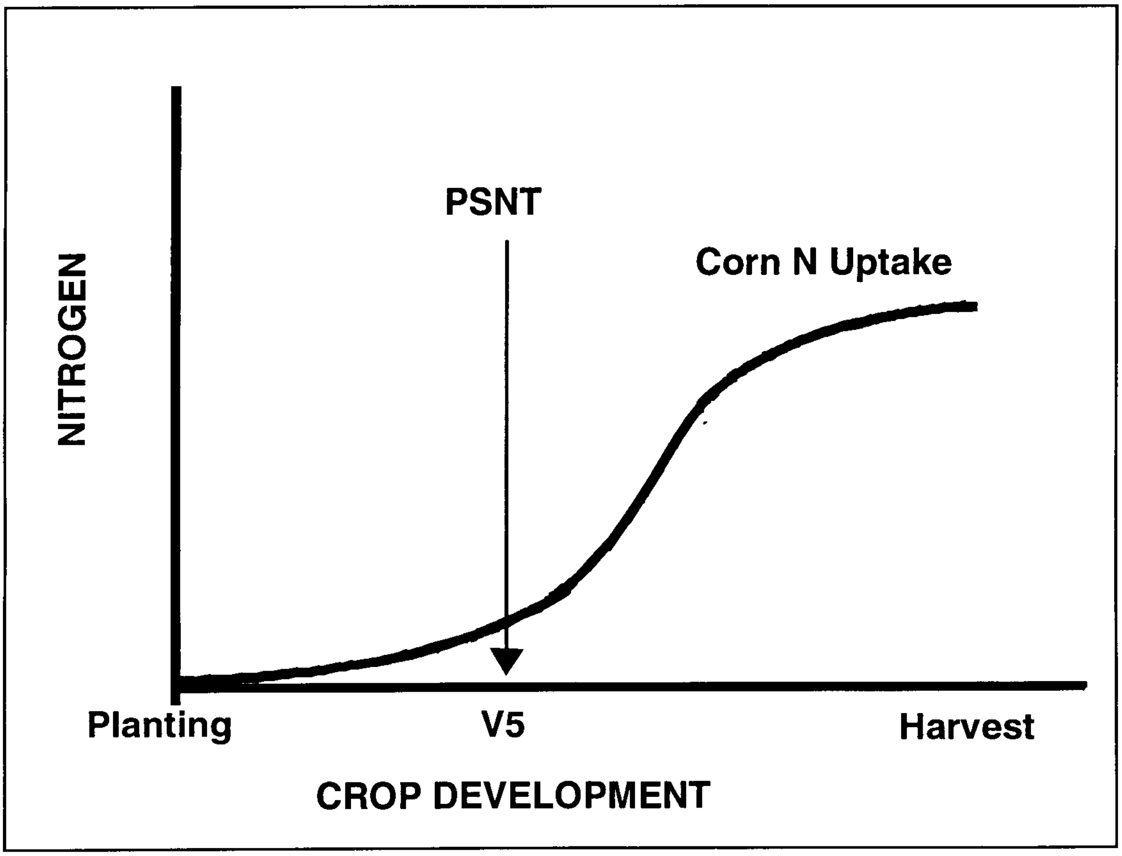

Fig. 1. Timing of PSNT in relation to corn nitrogen uptake.

Adoption of the PSNT method in the eastern U.S. has been slow, with the inconvenience of midseason sampling often cited as a deterrent. Soil test methods allowing for earlier sampling are desired. Soil nitrate at planting (SNAP) tests, though traditionally considered of little value, may provide useful information on sites with high manure inputs. Spring soil samples analyzed using the 200 nm absorbance of 0.01*M* $NaHCO_3$ soil extract method (UV200) proposed by Hong, et al., (1990) may also help in making earlier N management decisions.

A complete nitrogen monitoring program includes methods for post-harvest evaluation of N management efficiency. The amount of nitrate left in the soil after harvest is an indicator of both N management efficiency and potential leaching risk. As an alternative to soil testing, Binford et al. (1990) suggested that corn stalk nitrate concentration at harvest can be used as an indicator of N management efficiency.

The nitrogen monitoring techniques developed in the eastern United States have not been calibrated west of the Rocky Mountains. Willamette Valley production conditions differ from eastern conditions by having mild, wet winters and dry summers. Soils rarely freeze during winter, and corn producers rely heavily on irrigation to meet crop water demands during summer months. Also, manure handling practices in Oregon include the use of storage lagoons which are emptied onto fields during irrigation. Manure lagoon applications play a larger role in corn production in western Oregon than in rain fed agricultural regions.

The objective of this research was to determine if the PSNT, SNAP, UV205, residual soil nitrate, and corn stalk nitrate concentration at harvest tests can be used to evaluate crop nitrogen status in silage corn production in western Oregon. A secondary objective was to combine successful test methods to form a nitrogen monitoring program for use by producers. Use of a monitoring program will not only increase nitrogen management efficiency, but will also increase grower awareness of farm nitrogen dynamics. On-farm research focused on fields with a history of dairy manure applications.

LITERATURE REVIEW

Nitrogen and nitrates

Nitrogen (N) is the nutrient which most often limits plant growth. Nitrogen is a component of chlorophyll, nucleotides, and amino acids, which are the building blocks of proteins. Plants absorb N from the soil in the forms of ammonium (NH_4^+) and nitrate (NO_3^-). The NO_3^- form is dominant in warm, moist, well-aerated soils because microbial nitrification of NH_4^+ restricts NH_4^+ accumulation (Olson and Kurtz, 1982). Nitrate is a highly soluble anion and tends to remain in the soil solution. In soil solution, NO_3^- is susceptible to movement with water flow. Water flow may carry nitrates vertically through the soil profile via leaching or laterally in surface runoff. Leaching, surface runoff, plant removal, microbial immobilization, and denitrification are the primary mechanisms by which nitrate is lost from agricultural systems (Brady, 1990).

In agriculture, efficient nitrogen management is needed to protect both the environment and the economic viability of producers. Insufficient N supply can limit productivity. Excessive N applications not only represent unnecessary fertilizer expenditures but can also result in surface and ground water contamination.

Agricultural contributions to nitrate contamination of surface and ground waters have been an issue of great concern since the 1970s (NRC, 1978). In nitrogen limited aquatic systems, nitrate contamination can result in eutrophication. Nitrate in drinking water is a potential human health risk. Methemoglobinemia, or "blue baby syndrome" is a threat to infants under the age of about three months (Pierzynski et al., 1994). Young infants have bacteria in their digestive tracts which reduce nitrate to nitrite. Nitrite oxidizes iron in the hemoglobin molecule, forming methemoglobin. Methemoglobin cannot function in oxygen transport as hemoglobin does, and a symptom of the condition is a bluish coloration of the skin. After the age of 3 - 6 months, stomach acidity increases to a level that suppresses activity of the bacteria involved in the reduction of nitrate to nitrite, and methemoglobinemia risk declines. Nitrate induced methemoglobinemia does not normally occur in adults, and documented cases are rare even in infants. Separate studies in Germany found that 97% of infant methemoglobinemia cases were associated with drinking water containing more than 9 mg NO_3-N L^{-1} and 84% involved water containing more than 22 mg NO_3-N L^{-1} (NRC, 1978).

Environmental Protection Agency (EPA) standards require nitrate concentrations in drinking water to be less than 10 mg NO_3-N L^{-1} (USEPA, 1989). Results from a 1992 survey of nitrate in wells in the Willammette Valley are shown in Table 1.

Table 1. Results from March, 1992 well survey for nitrate in Willamette Valley counties. (from Oregon Department of Environmental Quality, 1992. Oregon's 1992 water quality assessment report. Report 305(b). p.4-56.)

County	Number of Wells Tested	Percent of Wells with >10 mg NO_3-N L^{-1}
Benton	107	0.9
Clackamas	882	0.8
Lane	502	1
Linn	250	2
Marion	173	5
Polk	30	7
Washington	167	4
Yamhill	89	3

The Oregon Department of Environmental Quality (DEQ) rates agricultural activities fourth in priority out of twelve major sources of groundwater contamination (Oregon DEQ, 1992). The three sources with greater priority are underground storage tanks, abandoned hazardous waste sites, and regulated hazardous waste sites. Nitrates, as well as some pesticides, are the potential agricultural contaminants of greatest concern.

Nitrogen in agriculture

Until the late 19th century, nitrogen for crop production was supplied by soil reserves, biological fixation, and cycling of N on the farm (Lanyon, 1995). Field application of domestic animal manures was a major component of farm N cycling. In the late 19th century, industrial N fixation methods were developed which allowed for the production of nitrogen fertilizers. Use of industrial N fertilizers led to large increases in crop productivity. Availability of fertilizers also allowed for less integrated farming systems, as on-farm nutrient cycling became unnecessary. Prior to 1850 almost all fertilizer nitrogen used in the United States was in the form of natural organic materials, but by 1980 these materials accounted for only 0.1% of total fertilizer nitrogen usage (Tisdale et al., 1985).

With increased use of industrial fertilizers, more specialized and intensive methods of crop and livestock production developed. Specialization occurred first on a farm-by-farm basis, and later on a regional basis. The result was the development of concentrated regions of N fertilizer use for crop production and regions of animal production with concentrations of N in feed (Lanyon, 1995). Because 70-75% of the N in feeds normally ends up in animal wastes (NRC, 1978), regions with large animal populations also generate large quantities of nitrogen in manure. Manure becomes a potential source of surface and groundwater pollution, as manure nutrient levels often exceed the capacity of the land for cycling.

Agricultural industrialization has not only led to regionalization of production, but also to fewer and larger farms. Since the development of commercial fertilizers, the number of dairy farms in the United States has decreased by more than 90% while dairy production has increased. Between 1959 and 1987, the percentage of the U.S. dairy herd living on farms with more than 100 cows increased from 7.2 to 42.3% (Lanyon, 1995). In Oregon between 1973 and 1992, the number of dairy cows increased from 93,000 to 102,000 while the number of dairy farms decreased from approximately 1,300 to 600 (USDA, 1993).

Over 48% of Oregon's $216 million dairy industry is concentrated in the Willamette Valley, which is home to approximately 50,000 milk cows (Table 2) (Miles, 1993). The Willamette Valley's 13,250 acres of silage corn helps feed the herds. Annually, dairy animals produce an estimated 1.5 million tons of manure containing 15.0 million pounds of nitrogen. If viewed as a fertilizer, this manure nitrogen has a value of approximately $4 million (Hart et al., 1995).

Table 2. Willamette Valley dairy industry component estimates, 1993.

Cows	50,000
Manure produced annually	1.5 million tons
Nitrogen in manure, annually	15.0 million pounds
Fertilizer value of N in manure, annually	$4 million
Corn silage acreage	13,250 acres
Corn silage N requirement	2.65 million pounds of N

Many of Oregon's silage corn producers refer to the OSU Fertilizer Guide for field corn (FG10) for N fertilizer rate recommendations. FG10 recommends 150 to 200 lb N/acre for irrigated corn following non-legume crops, and 80 to 100 lb N/acre for irrigated corn following legumes (Gardner and Jackson, 1983). Though many silage corn growers are dairy producers, FG10 makes no recommendation for reduced fertilizer applications on manured fields.

Crop N fertilization recommendations are often based on an N balance approach. In its simplest form, an N balance may be expressed as in Eq. 1 (Stanford, 1973).

$$N_f = \frac{N_{cr}}{e} - N_s \qquad [1]$$

where N_f = Fertilizer N requirement
N_{cr} = Crop N uptake
e = Crop N recovery efficiency
N_s = N supplied by soil

More complex N balance expressions include factors for N lost via leaching, surface runoff, denitrification, ammonia volatilization, and microbial immobilization (Meisinger, 1984).

The dynamic nature of the soil N pool makes the N_s factor in Eq. 1 difficult to evaluate, resulting in difficulties in making accurate fertilizer recommendations. Plants absorb N in the inorganic forms of NH_4^+ and NO_3^-. Approximately 97 to 99% of the N in soil is present in organic compounds (Dahnke and Johnson, 1990), and is thus unavailable for plant use. For organic N to become plant available, the organic compounds must be decomposed by soil microbes. Nitrogen mineralization is a biological process involving three steps: aminization, ammonification, and nitrification

(Tisdale et al., 1985). Aminization occurs during protein decomposition, and can be described as follows:

$$\text{proteins} \rightarrow R\text{-}NH_2 + CO_2 + \text{energy} + \text{other products}$$

The amines ($R\text{-}NH_2$) are then decomposed by microorganisms, resulting in the release of ammonia (NH_3) and ammonium (NH_4^+). The process of ammonification is described as follows:

$$\begin{array}{l} R\text{-}NH_2 + H_2O \rightarrow NH_3 + R\text{-}OH + \text{energy} \\ \qquad\qquad\qquad\quad \searrow {+H_2O} \\ \qquad\qquad\qquad\quad\;\; NH_4^+ + OH^- \end{array}$$

Finally, ammonium can be converted to nitrate in a two step process known as nitrification. In the first step, *Nitrosomonas* bacteria convert NH_4^+ to nitrite (NO_2^-). The second step involves the conversion of NO_2^- to NO_3^- by *Nitrobacter* bacteria. This two step process can be described by the following equations:

1) $2NH_4^+ + 3O_2 \xrightarrow{\mathit{Nitrosomonas}} 2NO_2^- + 2H_2O + 4H^+$

2) $2NO_2^- + O_2 \xrightarrow{\mathit{Nitrobacter}} 2NO_3^-$

The rate of N mineralization by microbes is difficult to predict due to its dependence on environmental factors such as temperature, moisture, aeration, type of organic matter, and pH. After mineralization, inorganic N is subject to immobilization, leaching, fixation, denitrification, and other losses (Dahnke and Johnson, 1990).

Soil tests for NO_3-N and NH_4-N measure plant available N at the time of sampling, but do not reflect N that is potentially mineralized or lost from the system later in the growing season. Use of pre-plant soil tests to estimate N_s has met with limited success in warm, humid regions where environmental conditions favor both mineralization and leaching. Meisinger et al. (1992b), however, believe there are opportunities to expand use of pre-plant tests. If conditions such as low winter precipitation, slowly permeable soils, or histories of excessive N inputs exist, then preplant soil NO_3-N tests may provide valuable information. Pre-plant soil nitrogen tests have been used successfully in arid regions.

Many attempts have been made to estimate mineralizable soil N using both chemical and biological methods. Extensive reviews of this research are available (Keeney, 1982; Meisinger, 1984; Stanford, 1981). Chemical methods have the advantage of being rapid, but are criticized as being unlikely to simulate microbial processes (Keeney and Bremner, 1966). Biological methods generally involve incubation periods ranging from 7 days (Waring and Bremner, 1964) to 12 weeks (Kresge and Merkle, 1957). Incubation procedures aim to induce microbial processes that may occur under field conditions. Nitrogen mineralized during incubation is measured and used as an index of soil N supplying capability. The length of time required for incubation procedures limits their practicality as both a laboratory method and management tool for use by farmers. Correlation of laboratory N mineralization estimates with plant N uptake in greenhouse studies has been successful (Keeney and Bremner, 1966; MacLean, 1964). Correlation of N mineralization indices with field data and crop response, however, has not been well established (Keeney, 1982; Fox and Piekielek, 1984). In Nebraska, Spencer et al. (1966) found that corn N uptake was correlated ($r = 0.79$) with initial soil NO_3^- plus nitrifiable N after two weeks of incubation, but concurrent research in Washington found no correlation.

Pre-sidedress Soil Nitrate Test

The Pre-sidedress Soil Nitrate Test (PSNT) for field corn addresses the difficulty in predicting soil N supplying capability by concentrating on the timing of soil testing, as opposed to the analytical procedure. An extensive review of early PSNT research is available (Bock and Kelley, 1992). The PSNT method involves minimal N applications at planting, followed by measurement of soil NO_3-N concentrations when plants are 15 to 30 cm tall (Magdoff et al, 1984). The 15 to 30 cm plant height coincides with the V5 or V6 growth stage, which is just prior to the period of rapid N uptake by corn (Ritchie et al., 1989) (Fig. 1, p. 2). The V5 and V6 growth stages are identified by the presence of five and six collared leaves, respectively. The 15 to 30 cm plant height also allows time for lab analysis and decision making before the plants are too tall for equipment to enter the field to apply sidedress fertilizer. By delaying soil sampling as long as possible, climatic and biological processes that influence N availability are allowed to occur *in situ* and are reflected in soil test results (Magdoff et al, 1984). Because the PSNT is designed to account for mineralized N, it is especially well-suited for manured fields with high organic N inputs (Fox et al., 1992).

The PSNT is used to predict whether additional N fertilization will result in increased yield. If the PSNT NO_3-N concentration is above an experimentally derived critical value, no response to N fertilization is expected and no additional N fertilization is recommended. If the PSNT is below the critical value, additional N is expected to increase yields. PSNT critical values in 17 eastern and midwestern states range from 19 to 30 ppm NO_3-N, with 10 states reporting a critical value of 25 ppm

NO_3-N (Woodward et al., 1993). There are no published PSNT critical values for states west of the Rocky Mountains.

The PSNT error rate refers to the percentage of sites where the PSNT did not correctly predict N fertilizer response on research plots. There are two types of error. Type I errors are sites where the PSNT value was below the critical value but no response to N fertilizer was observed. Type II errors are sites where the PSNT value was above the critical level and an unexpected response to N fertilizer was observed. Type II errors are considered of greater concern to growers, as they represent situations where a decision to forgo fertilization results in lost yield. Growers are unlikely to use a soil test that does not consistently identify the potential for increased yields from N fertilization (Fox et al., 1992). Combined research in the Mid-Atlantic region involving 221 experiments found a PSNT total error rate of 18.1%, with 2.3% being type II errors.

Pennsylvania researchers found a PSNT error rate of 34.1% on 41 sites where corn was grown following a legume. With one exception, all errors were low PSNT, non-responding sites. This indicates that legume N may have been mineralized after PSNT sampling but early enough for crop utilization, and raises questions regarding use of the PSNT following legumes (Fox et al., 1992).

Although the PSNT is successful at identifying N responsive and non-responsive sites, the test has limited value as a tool for making accurate fertilizer rate recommendations. This is due to the poor correlation between PSNT soil NO_3-N concentrations and relative yield on N responsive sites (Fox et al., 1989; Klausner et al., 1993; Magdoff et al., 1992; Meisinger et al., 1992). As a result, the PSNT can be used with confidence to determine whether or not additional N is needed, but there is little confidence in knowing how much N to apply if fertilization is required. Nevertheless, many states do publish N rate recommendations based on PSNT values and yield potential (Beegle et al., 1990; Bundy and Sturgel; Magdoff et al., 1990). In Vermont, recommendations are based on the following equation (Magdoff et al., 1990):

$$NF = [YP - (PSNT/1.84)] * 10.7 \qquad [2]$$

where NF = sidedress N fertilizer recommendation (kg ha^{-1})
YP = silage DM yield goal (Mg ha^{-1})
$PSNT$ = PSNT soil test (mg NO_3-N kg^{-1})

Though data on the implications of the PSNT on management practices is limited, nine states where the PSNT has been adopted reported that N fertilizer application rates were reduced by an average of 25 to 30%, or 30 to 50 lbs. of fertilizer N per acre (Woodward et al., 1993). On-farm research in Iowa compared fertilizer inputs based on a late-spring soil nitrate test to farmers' normal practices. In 1989, the soil test enabled farmers to reduce N fertilizer by an average of 62% without yield reductions. In 1990, similar research found a 21% average fertilizer reduction was possible (Blackmer et al., 1992).

While the PSNT is an effective tool for improving nitrogen management for field corn, adoption of the method has been slow. The inconvenience of performing a soil test at a different time of year from routine fall or spring soil testing and the need for rapid lab turnaround times are often cited as deterrents to PSNT utilization (Magdoff, et al., 1990). Many growers prefer to make fertilizer management decisions prior to planting, and do not want to wait until June or July as required by the PSNT. On dairies, where management of animals is of higher priority than field crop management, convenience of soil testing programs may be especially important. To address this situation, attempts have been made to develop methods for identifying N responsive and non-responsive sites at an earlier date than is possible with the PSNT. Measurement of 200 nm absorbance of 0.01*M* $NaHCO_3$ soil extract is one such method.

UV205 method

MacLean (1964) used a 0.01*M* $NaHCO_3$ solution to extract easily solubilized organic compounds from soils. The nitrogen content of the 0.01*M* $NaHCO_3$ extract as determined by the Kjeldahl method was used to estimate soil nitrogen supplying capability (NSC). Actual NSC was determined by N uptake of ryegrass in greenhouse experiments. MacLean's estimation method was more highly correlated with actual NSC (r = 0.85) than other methods tested. Fox et al. (1978a) found MacLean's method to be well correlated (r = 0.77) with soil NSC in field corn experiments.

The strong absorbance band of NO_3^- at 203 nm can be used to determine NO_3^- concentrations in solution with a high degree of accuracy and precision (Bastian et al., 1957). Cawse (1967) used UV absorbance to determine nitrate concentrations in soil solutions. When attempting to analyze NO_3^- in soil extracts using 203 nm absorbance, Cawse experienced problems due to interferences from non-nitrate substances such as Cl^-, NO_2^-, Fe^{3+}, and organic matter which also absorb at 203 nm. The problem was partly alleviated by measuring absorbance at 210 nm, which is sensitive to NO_3^- but less sensitive to most non-nitrate substances. At 210 nm, organic substances were the primary source of interference. Cawse suggested an alumina cream suspension treatment to remove interfering organics.

Norman et al., (1985) developed a dual wavelength method for determining nitrate concentration in soil extract based on absorbance at 210 nm and 270 nm. Organic matter compounds absorb strongly at both 210 nm and 270 nm, whereas NO_3^- does not absorb at the higher wavelength. To correct for non-nitrate species absorbing at 210 nm, an empirically determined multiple of absorbance at 270 nm was subtracted from 210 nm absorbance. Soil NO_3^- analysis using the dual wavelength absorbance method was highly correlated ($r^2 = 0.999$) with a conventional steam distillation method of NO_3^- analysis. Results using the dual wavelength method were sensitive to large non-nitrate background caused by organic amendments or transition metals, and caution was advised in using the method to determine NO_3^- concentrations in manure amended soils.

Fox et al. (1978b) modified MacLean's method (MacLean, 1964) and measured 260 nm absorbance of $0.01M$ $NaHCO_3$ soil extract to predict soil NSC. In MacLean's original method, $NaHCO_3$ was used to extract easily solubilized organic compounds. The N content of the extract containing the organic compounds was then determined by the Kjeldahl method. Norman (1985) found the 260 nm absorbance of soil extract was an indicator of organic matter content. In modifying MacLean's method, Fox was using extractable organic matter to estimate extractable organic N. Fox's method assumes a constant C:N ratio between mineral soils. Fox et al. (1978b) found a strong correlation ($r = 0.91$) between $0.01M$ $NaHCO_3$ extractable N and 260 nm absorbance, suggesting the constant C:N ratio assumption is valid. Fox et al.

modified MacLean's method because 260 nm absorbance is easier to measure than Kjeldahl N. The 260 nm absorbance of 0.01*M* $NaHCO_3$ soil extract was well correlated (r = 0.865) with soil NSC in field corn experiments. Soil NSC was defined as the N content in corn grown on plots receiving no N other than starter fertilizer, minus 75% of the starter fertilizer N applied.

Hong et al. (1990) further modified MacLean's method and measured 200 nm absorbance of 0.01*M* $NaHCO_3$ soil extract to predict soil NSC. As stated earlier, Cawse (1967) found that both NO_3^- and organic compounds absorb at 200 nm. If 0.01*M* $NaHCO_3$ extractable organic matter reflects the mineralizable N pool (MacLean, 1964), then 200 nm absorbance of 0.01*M* $NaHCO_3$ extract containing both solubilized organic matter and extracted NO_3^- was hypothesized to reflect soil NSC. By measuring both NO_3^- and solubilized organic matter at the same time, Hong et al. were able to take advantage of the fact that both NO_3^- and organic compounds absorb at 200 nm. What was previously considered interference became an asset.

The 200 nm absorbance method was found to be a slightly better predictor of soil NSC (r = 0.73) than the PSNT (r = 0.67) in 49 experiments with field corn (Hong et al., 1990). Soil NSC was defined as for Fox et al. (1978b), stated previously.

In a comparison of the ability of the 200 nm absorbance and PSNT methods to identify N responsive sites in 121 field corn experiments, the 200 nm absorbance method had a correct prediction rate of 79.3% (critical value = 1.51 absorbance units) while the PSNT had a correct prediction rate of 81.0% (critical value = 22 mg NO_3-N kg^{-1} soil) (Fox et al., 1992). Eliminating the 27 experiments following a legume, both the 200 nm absorbance and PSNT methods had a correct prediction rate of 86.2%. In a later study, the 200 nm absorbance method had a 81.1% correct prediction rate compared to 88.9% for the PSNT (Fox et al., 1993). The advantages of the 200 nm absorbance method are that soil can be sampled earlier in the season and a sampling depth of 20 cm, as opposed to 30 cm for the PSNT, is sufficient.

Residual soil nitrate

As stated earlier, potential groundwater contamination resulting from nitrate leaching is an issue of great concern. Leaching risk is greatest during winter months when high rainfall and low levels of evapotranspiration result in increased percolation of water through soil profiles (Chichester, 1977). One factor which helps determine the magnitude of leaching risk is the amount of residual soil nitrate (RSN) in the soil after crop removal.

Roth and Fox (1990) found that RSN accumulation following corn harvest was affected by both N fertilization rate and field history. RSN accumulation was greatest at high N fertilization rates, as N supply exceeded crop demand. When fertilized at economically optimum N rates, average RSN was higher on sites with a history of manure applications (94 kg NO_3-N ha^{-1}) than on non-manured sites (74 kg NO_3-N ha^{-1}). The higher RSN accumulations on manured sites were attributed to greater mineralization of organic residues in manured fields during the period between the end of N uptake by corn and soil sampling. Thus, the temporal pattern of the inorganic N supply influences RSN, as N availability must coincide with plant demand. Nitrogen mineralized late in the growing season, when plant demand is low, is more likely to be left unused by the plant than N which is available during periods of peak demand.

RSN is a function of both N supplied to the crop and crop N utilization efficiency (Chichester, 1977). Crop N utilization efficiency is a measure of the ability of the crop to scavenge N in soil solution. Even with good management practices, RSN is likely to be higher following production of N-inefficient crops as compared to production of N-efficient crops.

RSN in the surface 30 cm of soil can sometimes be used as an indicator of soil profile NO_3-N accumulation (Herron et al., 1968; Roth and Fox, 1990). Roth and Fox (1990) reported that soil NO_3-N accumulation in the surface 30 cm was highly correlated ($r = 0.90$) with NO_3-N in the 120 cm profile. They suggested that NO_3-N accumulation in the surface 30 cm could be used to identify sites with high potential for NO_3-N leaching. The degree to which surface NO_3-N reflects accumulation in the profile is dependent on factors such as irrigation practices and water infiltration rates (Stanford, 1982).

Corn stalk nitrate

The nitrate concentration in the lower portion of a corn stalk is dependent on the stage of maturity of the crop, soil nitrogen availability, and degree of drought stress (Hanway et al., 1958). Nitrate typically accumulates in the lower stem internodes of corn prior to silking (Friedrich et al., 1979). After silking, stalk NO_3-N may be mobilized and assimilated in the grain, especially if the soil N supply is limited. The stalk nitrate concentration decreases as the plant matures, though the degree of decline depends on environmental conditions. If corn is grown in conditions of drought or excessive nitrogen supply, nitrate concentrations in the base of the stalk may remain elevated (Hanway et al., 1958). Stalk nitrate concentrations were originally of concern due to potential nitrate poisoning of livestock feeding on drought stressed or excessively fertilized forage. More recently, stalk NO_3-N concentration measured at harvest has been used as a tool for evaluating N management in field corn.

Binford et al. (1990) examined the relationship of stalk nitrate concentrations in 20 cm sections of stalk (15 to 35 cm above the ground) at harvest to grain yields and rates of N fertilization. Time of sampling was within 10 days after black layers were present on most kernels of most ears, which indicates physiological maturity. At N rates *below* that necessary to obtain maximum yield, increasing N rates resulted in increased yield without changing stalk NO_3-N concentrations. At rates of fertilization *above* that necessary to obtain maximum yield, stalk NO_3-N concentrations increased linearly with increasing N fertilizer rates. A critical stalk NO_3-N concentration of 0.25 g NO_3-N kg^{-1} was determined using a linear-response-and-plateau (LRP) model. Stalk NO_3-N concentrations above the critical level indicated N was supplied at rates in excess of that necessary to obtain maximum yield. Analyzing the same data using an economic optimum rate of fertilization model (EOM), the critical concentration was 1.80 g NO_3-N kg^{-1}. Stalk NO_3-N concentrations above the critical level for the EOM model indicated the cost of additional N was greater than the increase in value of the harvested crop. The higher critical level resulting from use of the EOM model as opposed to the LRP model was due to a slight increase (+5.5%) in average yields as stalk NO_3-N concentrations increased from 0.25 to 1.80 g NO_3-N kg^{-1}. In order to achieve this 5.5% yield increase, however, the mean rate of fertilizer N application increased from 100 to 181 kg N ha^{-1}. In addition to economic returns, a more complete analysis might include an evaluation of residual soil nitrate and resulting environmental risks associated with the increased fertilizer N rates.

Binford et al. (1990) combined the LRP and EOM analyses to identify an optimal stalk nitrate critical range of 0.25 to 1.80 g NO_3-N kg^{-1}. With the addition of data from later studies, the optimal range was revised to between 0.70 and 2.00 g NO_3-N kg^{-1} (Binford et al., 1992b). The differences in the ranges were explained by fluctuations in the prices of corn and fertilizer as well as drought-affected corn in the second data set. While drought conditions did affect stalk NO_3-N concentrations, adjusting critical ranges to account for rainfall did not significantly improve the usefulness of the tissue test. Sims et al. (1995) found the 0.70 to 2.00 g NO_3-N kg^{-1} critical range applied to Delaware grain corn production, as well.

Relationships between stalk Kjeldahl-N concentrations and grain yield and N fertilization were similar to those noted for stalk NO_3-N concentrations (Binford et al., 1990). Kjeldahl-N critical levels were 2.93 g N kg^{-1} using the LRP model and 4.31 g N kg^{-1} using the EOM model. Stalk NO_3-N analysis is cheaper and easier to perform than Kjeldahl-N analysis and was considered preferable.

Stalk nitrate tests have also been considered as potential tools for monitoring the N status of a young corn crop. Research, however, found that stalk NO_3-N concentrations of young corn plants are not an accurate predictor of soil N availability or responsiveness to N fertilization (Fox et al., 1989; McClenahan and Killorn, 1988). The influence of environmental factors such as solar radiation and soil moisture availability resulted in large variations in stalk NO_3-N concentrations (Fox et al., 1989). Reduced solar radiation prior to sampling increased stalk NO_3-N concentrations, while reduced soil moisture availability decreased NO_3-N concentrations. Schepers et al. (1990) investigated cultivar effects on stalk NO_3-N concentrations at the V6 growth stage. Differences between hybrids were not discernable due to large variations within hybrids in both years of a two year study.

MATERIALS AND METHODS

Experiment sites

Twenty-six experiments were conducted on 17 farms in the Willamette Valley of western Oregon during a two year period (1993-1994). Twenty-three of the experiments were located on manured dairy farm fields. The dairies employed a variety of manure handling practices including the spreading of solid manure, application of liquid manure prior to planting, and fertigation with manure lagoon water during the growing season. Some dairies with lagoons flushed both solid and liquid fractions into the lagoon while others used separators to remove the solid fraction of the manure. Site locations, manure histories, and soil types are presented in Table 3.

The Willamette Valley has a Mediterranean climate, with cool, wet winters and hot, dry summers. Annual rainfall is approximately 1000 mm, with 650-700 mm falling between November and April. The spring of 1993 was unusually wet, resulting in planting dates later than normal (Table 4). In 1994, precipitation more closely approximated the long term average, and planting dates were earlier than for 1993.

Treatments

Each experiment consisted of two treatments replicated four times. Each plot was four to six rows in width and 8 meters in length. Treatments were randomly assigned to plots when corn was at the V5 or V6 growth stage. The treatments were: (1) no additional fertilizer applied, or (2) 200 kg N ha^{-1} sidedressed as urea. Each

Table 3. Site locations, manure histories, and soil types

Site No.	Year	County	Manure History	Irrigation Water	Soil Series	Soil Texture	Soil Classification
1	1993	Marion	Yes	Clean	Concord	silt loam	Typic Ochraqualfs
2	1993	Yamhill	Yes	Clean[a]	Woodburn	silt loam	Aquultic Argixerolls
3	1993	Yamhill	No	Clean	Amity	silt loam	Argiaquic Xeric Argialbolls
4	1993	Yamhill	Yes	Lagoon	Woodburn	silt loam	Aquultic Argixerolls
5	1993	Washington	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls
6	1993	Washington	Yes	Lagoon[b]	Woodburn	silt loam	Aquultic Argixerolls
7	1993	Washington	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls
8	1993	Polk	Yes	Lagoon	Helvetia	silt loam	Ultic Argixerolls
9	1993	Polk	Yes	Lagoon	Helvetia	silt loam	Ultic Argixerolls
10	1993	Marion	Yes	Lagoon	Woodburn	silt loam	Aquultic Argixerolls
11	1993	Marion	Yes	Lag & Clean[c]	Amity	silt loam	Argiaquic Xeric Argialbolls
12	1993	Linn	Yes	Clean	Chehalis	silty clay loam	Cumulic Ultic Haploxerolls
13	1993	Linn	Yes	Lagoon	Coburg	silty clay loam	Pachic Ultic Argixerolls
14	1994	Clackamas	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls
15	1994	Clackamas	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls
16	1994	Clackamas	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls
17	1994	Clackamas	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls
18	1994	Marion	Yes	Clean	McAlpin	silty clay loam	Cumulic Ultic Haploxerolls
19	1994	Washington	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls
20	1994	Washington	Yes	Clean	Aloha	silt loam	Aquic Xerochreptic
21	1994	Marion	No	Clean	Cloquato	silt loam	Cumulic Ultic Haploxerolls
22	1994	Marion	Yes	Clean	Amity	silt loam	Argiaquic Xeric Argialbolls
23	1994	Polk	No	Clean	Willamette	silt loam	Pachic Ultic Argixerolls
24	1994	Marion	Yes	Lagoon	Woodburn	silt loam	Aquultic Argixerolls
25	1994	Clackamas	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls
26	1994	Clackamas	Yes	Clean	Woodburn	silt loam	Aquultic Argixerolls

a - Field had history of manure lagoon irrigation, but was irrigated with clean water in 1993.

b - Field had history of clean water irrigation, and was irrigated with manure lagoon water for the first time in 1993.

c - Irrigated with manure lagoon water during early season and clean water during late season.

Table 4. Growing season climatic data for 1993, 1994, and 30 year average (1961-1990). Data recorded at Hyslop Experiment Station, Corvallis, OR. Growing degree days (GDD) are calculated at 10° C . Precipitation (Ppt.) is reported in millimeters.

	April		May		June		July		August		September		Season Total	
	GDD	Ppt.	GDD	Ppt.	GDD	Ppt.	GDD	Ppt.	GDD	Ppt.	GDD	Ppt.	GDD	Ppt.
1993	24	173	152	115	172	54	217	20	296	8	211	2	1929	372
1994	46	49	125	28	157	48	309	0	276	0	243	23	2081	148
30 yr. ave.	32	65	90	50	182	31	269	13	278	22	194	38	1882	219

grower managed the corn fields containing the experimental plots according to normal practices with the exception that no additional commercial fertilizer was applied to the plots by the grower after the planting date.

Soil sampling

Soil was sampled three times in 1993 and four times in 1994 at the times and depths described in Table 5. All soil samples were composites of 12 to 15 cores.

Table 5. Soil sampling schedule.

Year	Sample Number	Time of sampling	Depth of sampling
1993	1	June, near time of planting	0 to 150 cm in 30 cm increments
	2	Corn at V5 or V6 growth stage (PSNT sample)	0 to 30 cm
	3	October, post-harvest	0 to 150 cm in 30 cm increments
1994	1	May, near time of planting	0 to 150 cm in 30 cm increments
	2	June, after planting	0 to 30 cm
	3	Corn at V5 or V6 growth stage (PSNT sample)	0 to 30 cm
	4	October, post-harvest	0 to 150 cm in 30 cm increments

Post-harvest samples were collected separately from 0 kg N ha^{-1} and 200 kg N ha^{-1} treatments. Samples from each treatment consisted of composites of 12 cores, three from each of the four replicates. Profile sampling to depths of 150 cm in 30 cm increments was performed with a Kauffman soil sampler (Marvin Kauffman, Albany, OR), which makes use of a hydraulic auger. Surface samples from 0 to 30 cm (1993 sample 2, 1994 samples 2, 3) were collected using a stainless steel soil sampling probe. All samples were immediately placed in a cooled ice chest and transported to Oregon State University. At Oregon State University, samples were either frozen or placed in drying cabinets at 35°C the same day as collected.

In 1994 only, a soil sample (no. 2) from 0 to 30 cm was collected shortly after planting to determine soil NO_3-N concentrations following at-planting fertilizer applications made by growers. This sample was used for SNAP and UV205 analysis in 1994.

Soil analysis

Soil analyses were performed in the OSU Central Analytical Laboratory (Oregon State University, 3079 Ag-Life Sciences Building, Corvallis, OR). All soil samples were dried in forced air drying cabinets at 35°C, ground to pass through a 2 mm sieve, and extracted with 2 N KCl (4:15 soil:solution). Extracts were analyzed colorimetrically for NH_4^+-N (salicylate/nitroprusside method) and NO_3^--N (diazotization following Cd reduction) using a continuous flow analyzer (ALPKEM^{TM} RFA-300 Analyzer, Perstorp Analytical, Wilsonville, OR) as described by Horneck et al. (1989). The method used by the OSU Central Analytical Laboratory is a modification of the method described by Keeney and Nelson (1982). A standard deviation of 0.068 mg NH_4^+-N L^{-1} was determined when a 4.00 mg NH_4^+-N L^{-1} standard was analyzed ten times using the ALPKEM^{TM} RFA-300 Analyzer. Similarly, a standard deviation of 0.03 mg NO_3^--N L^{-1} was determined from analysis of a

4.00 mg NO_3^--N L^{-1} standard (Hanson, 1993). In fifty analyses of a laboratory reference soil sample, means of 14.3 ± 0.967 mg NH_4^+-N kg $^{-1}$ and 4.3 ± 0.277 mg NO_3^--N kg $^{-1}$ were measured.

Soil profile NH_4^+-N and NO_3^--N data for at-planting and post-harvest samplings are shown in Appendix 1. PSNT NH_4^+-N and NO_3^--N data are shown in Appendix 2. The NH_4^+-N and NO_3^--N data for 1994 sample no. 2 are shown in Appendix 3.

Soil samples 1993 no. 2 and 1994 no. 1 (0 - 30 cm) were analyzed for extractable potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P), and pH. Extractable K, Ca, and Mg were determined by the ammonium acetate method. Extractable P was determined by the Bray-P1 method. Soil pH was determined using a 1:2 soil to water ratio and a pH electrode (Horneck et al., 1989). Extractable P, Ca, K, Mg and pH data are presented in Appendix 4.

Extractable P and K in the 150 cm profile at 30 cm increments were determined for 1993 sample no. 1. Profile P and K data are presented in Appendix 5.

Corn dry matter yield

Corn was harvested at the R3/R4 stage or approximately one week prior to the grower's scheduled harvest, whichever came first. Corn plants from the center four meters of the center two rows of each plot were harvested and weighed in the field. Five plants from each plot were passed through a chopper onto a tarp. The chopped material was subsampled and analyzed for moisture content and Total Kjeldahl Nitrogen (TKN). Percent relative yield (RY) based on dry matter (DM) was calculated for each experiment using Eq. 3. The site mean moisture content was used

$$\frac{(mean\ DM\ yield\ 0\ kg\ N\ ha^{-1}\ treatment)}{(mean\ DM\ yield\ 200\ kg\ N\ ha^{-1}\ treatment)}\ X\ 100 = \%\ RY \qquad [3]$$

to calculate dry matter yield for each plot because it was considered a better estimate of the true moisture content than the moisture content of an individual plot sample. Statistical analysis determined there was no treatment effect on moisture content.

Plant Total Kjeldahl Nitrogen

Plant total N content was determined by the Kjeldahl method in the Central Analytical Laboratory, Oregon State University. Plant material was oven dried at 60°C, then ground in a Wiley mill with a 20 mesh screen. For digestion, 0.2500 g plant material was placed in a 75 mL volumetric digestion tube with 1.0 g catalyst (100 g K_2SO_4 : 5 g $CuSO_4$: 1 g Se) and 8 mL concentrated H_2SO_4. Tubes were placed on a block digester for 80 minutes at 120°C followed by 3 hours 50 minutes at 350°C. Cooled digests were brought to 75 mL volume and analyzed colorimetrically for NH_4^+-N (salicylate/nitroprusside method) using an ALPKEM^{TM} RFA-300 Analyzer.

TKN data was normalized by calculating percent relative TKN (Eq. 4).

$$\%\ Relative\ TKN = \frac{\%TKN\ [0\ kg\ N\ ha^{-1}\ treatment]}{\%TKN\ [200\ kg\ N\ ha^{-1}\ treatment]}\ X\ 100 \qquad [4]$$

Protein concentrations were estimated by multiplying TKN by 6.25 (Holland and Kezar, 1990).

The amount of N removed in the crop was calculated as shown in Eq. 5.

$$\frac{kg\ N\ removed}{ha} = \%TKN\ X\ \frac{kg\ DM\ yield}{ha} \div 100 \qquad [5]$$

Corn stalk nitrate

At harvest, a 20 cm section of stalk beginning approximately 15 cm above ground level was cut from ten corn plants from each plot. The outside leaves were removed and the stalks were split lengthwise to aid in drying. Split stalks were oven dried at 50°C, then ground in a Wiley mill with a 20 mesh screen. Nitrate-N concentration was determined by shaking 0.2000 g of plant material in 20 mL of 2% acetic acid for 45 minutes, filtering through Whatman no. 42 paper, and analyzing the filtered extract using an ALPKEM^{TM} RFA-300 Analyzer following Cd reduction (Horneck et al., 1989). Samples with NO_3^--N concentrations >2200 ppm were diluted 10X with 2% acetic acid.

UV205 method

The procedure for the UV205 method was a modification of the procedure described by Fox and Piekielek (1978). Soil sampled from 0 to 30 cm at planting (sample no. 1, 1993) or shortly after planting (sample no. 2, 1994) was dried and ground to less than 2 mm. Fifty mL 0.01*M* $NaHCO_3$ was added to 2.5 g soil and shaken for 15 minutes. Following shaking, the solution was filtered through Whatman no. 42 filter paper. Ten mL of extract was pipetted into a plastic test tube and acidified with 100 µL concentrated HCl to eliminate HCO_3^-. Acidified extracts were vortexed. The 205 nm absorbance of acidified extracts was measured using a dual beam spectrophotometer and 1 cm quartz cuvets. Blank 0.01*M* $NaHCO_3$ solution that had been passed through filter paper and acidified was used as the reference solution. Nitrate standards were prepared in distilled H_2O, 0.01*M* $NaHCO_3$, and acidified 0.01*M* $NaHCO_3$.

Statistical analysis

T-tests were used to evaluate treatment effect on DM yield, TKN, and N removed in crop within each experiment. Simple linear regression analysis was used to determine correlations between test methods. T-tests and regression analyses were performed using Number Crunching Statistical Software version 5.03 (NCSS, Kaysville, Utah) and the Quattro Pro 6.0 Spreadsheet program (Borland International, Inc., Scotts Valley, CA).

The Cate-Nelson (CN) procedure (Cate and Nelson, 1971) was used to determine critical values for each of the N management methods evaluated. CN analysis was performed using the Quattro Pro 6.0 spreadsheet program. Percent relative DM yield (Eq. 3) and percent relative plant TKN (Eq. 4) were calculated to normalize data and allow for among site comparisons. A brief description of the CN procedure is as follows (refer to Tables 7 and 8 on pp. 37-38 for an example of CN analysis):

CN analysis is an iterative process that separates data into two populations. Data is first ranked by increasing independent variable (X-axis) values. In this research, the independent variable was a soil or plant analysis value. The data are then systematically divided into two populations, beginning by placing the two lowest X-values in population 1 and all others in population 2. The next iteration places the three lowest X-values in population 1 and all others in population 2. Next, the four lowest X-values are placed in population 1, and so on. This iterative process continues until all possible separations have been tested. The critical value being tested at each iteration is located halfway between the highest value in population 1 and the lowest value in population 2.

At each iteration, the means of the response variable (Y-axis) of populations 1 and 2 are calculated, as are the sums of squares of deviations from those means. The total corrected sum of squares (TCSS) of deviations from the mean of the entire data set is also calculated. These sums of squares values are used to calculate an r^2 value as shown in Eq. 6. The critical value with the highest r^2 value is the value that best divides the data into two populations. In this research, the two populations were N responsive and N non-responsive sites.

$$r^2 = \frac{TCSS - (CSS1 + CSS2)}{TCSS} \qquad [6]$$

where $TCSS$ = Total corrected sum of squares
$CSS1$ = Corrected sum of squares, pop. 1
$CSS2$ = Corrected sum of squares, pop. 2

Acceptable r^2 values in CN analysis are typically much lower than those encountered in regression analysis. For an r^2 value of 1.00, all values in population 1 must be identical and all values in population 2 must be identical. This is not the expected case in a soil fertility experiment. The non-responsive sites will cluster around 100% relative yield, but the responsive sites will have a range of relative yields, generally approaching 100% near the critical level and declining as the nutrient test value declines. The role of the r^2 value in CN analysis is to determine the best point of separation of the two populations, and whether the highest r^2 value approaches 1.00 or is quite low is of relatively little importance.

After the statistical procedure has been performed, the data are plotted with test values on the X-axis and percent relative yield on the Y-axis (Fig. 2, p. 39). A vertical line is drawn intersecting the X-axis at the CN critical value. A horizontal line dividing responsive (points below line) and non-responsive (points above line) sites is drawn intersecting the Y-axis. A number of methods can be used to determine the Y-intercept. Often, a relative yield of 93-95% is arbitrarily chosen to represent a balance between satisfying crop nutrient requirements and avoiding excessive fertilizer applications (Meisinger et al., 1992). In this research, a Y-intercept of 94% relative yield was used. An alternative method for determining the Y-intercept is economic analysis to determine the economic optimum yield. The economic optimum yield is often less than 100% due to the diminishing rate of returns encountered as fertilizer inputs increase. Economic analysis could also be combined with analysis of environmental risks to determine an optimum relative yield.

RESULTS & DISCUSSION

Pre-sidedress Soil Nitrate Test

Soil NO_3-N concentrations measured when corn was at the V5/V6 growth stage and dry matter (DM) yield data are presented in Table 6. PSNT values ranged from 7 to 81 mg NO_3-N kg^{-1}. The wide range of soil NO_3-N concentrations reflects differences in manure application histories. Soil NO_3-N concentrations tended to be higher on sites with long histories of intensive manure application.

Maximum DM yields ranged from 9.1 to 21.9 Mg ha^{-1}. The differences in productivity among sites could be due to factors such as irrigation, corn cultivar, crop rotation, climatic variables, planting and harvesting dates, soil types, and a host of management practices affecting soil physical and biological properties.

For 7 of the 26 experiments, relative yields for unfertilized plots were less than 94% and were thus identified as N responsive for Cate-Nelson (CN) analysis. Percent relative yield was calculated to normalize data to allow for between site comparisons. For within site comparisons, yield differences due to treatments can be identified using t-tests. T-tests identified four sites with significant yield increases with added N (P-value < 0.05) (Table 6). All four sites with statistically different yields also had percent relative yields less than 94%, and were thus identified as responsive in CN analysis. Three sites (12, 15, 18) had relative yields less than 94% but yields which were not statistically different using t-tests. Yield data for two of these sites (12, 15) had relatively high C.V.'s, which reduces the ability of the t-test to detect differences.

Table 6. T-test analysis of corn dry matter yield data. Sites are listed in order of increasing PSNT values (mg NO_3-N kg^{-1} soil). ** Significant difference between treatments at $P < 0.01$.

Site No.	PSNT (mg NO_3-N kg^{-1})	Dry matter yield (Mg ha^{-1}) 0 kg N ha^{-1}	Dry matter yield (Mg ha^{-1}) 200 kg N ha^{-1}	C.V. (%)	rel. yld. (%)	T-test P-value
12	7	10.4	11.6	11.0	89.8	0.22
15	16	8.5	9.5	14.0	90.8	0.37
21	16	18.8	21.6	5.2	86.7	0.01 **
3	18	12.8	13.7	2.3	93.6	0.01 **
8	23	12.8	13.0	6.9	98.5	0.76
1	25	18.4	17.9	5.9	102.9	0.52
22	28	9.1	9.0	7.1	101.5	0.66
6	28	16.4	16.8	4.2	97.7	0.63
14	33	16.8	18.6	3.3	90.3	0.00 **
5	35	16.1	16.4	8.1	98.2	0.76
7	35	15.4	15.8	4.2	97.4	0.41
2	37	19.3	18.4	8.7	104.9	0.47
16	38	13.5	13.2	4.4	102.7	0.42
13	39	11.1	11.6	4.6	95.6	0.21
23	40	20.7	21.9	6.9	94.5	0.30
17	41	10.3	10.2	8.4	101.0	0.87
11	46	13.4	13.9	5.7	96.4	0.40
10	47	14.5	16.4	4.9	88.6	0.01 **
24	52	16.4	16.4	7.0	99.6	0.94
9	55	20.0	20.9	6.2	95.7	0.17
20	55	14.2	13.3	8.0	107.0	0.47
18	56	17.7	19.2	5.5	92.1	0.08
19	57	16.6	15.4	5.1	107.9	0.08
25	62	12.9	12.8	7.5	100.5	0.93
4	64	13.0	12.4	11.3	105.1	0.56
26	81	13.2	13.3	6.3	99.1	0.85

CN analysis determined a PSNT critical value of 21 mg NO_3-N kg^{-1} soil (Tables 7, 8). The CN plot shows the PSNT correctly identified 23 of the 26 site-years as N responsive or N non-responsive (Fig. 2). The three incorrect predictions resulted in an error rate of 12%. Similar critical values and error rates were found in research in other regions of the United States (Fox et al., 1992; Klausner et al., 1993; Magdoff et al., 1984).

The only incorrect prediction in 1993 was site 10 with a PSNT value of 47 mg NO_3-N kg^{-1} and an unexpected yield response to additional N (Fig. 2). The plots had been placed in a slight swale which may have had an effect on crop performance. In 1994, site 24 was established in the same field, but in a more representative location. Site 24 had a PSNT value of 52 mg NO_3-N kg^{-1} and was non-responsive, as predicted.

The distribution of PSNT values lends insight into trends in soil N on manured dairy fields. Twenty-three of the 26 sites had a history of manure application. Of the 23 manured sites, only 2 (9%) had PSNT values less than the 21 mg NO_3-N kg^{-1} critical value. Both of the manured fields with low PSNT values were located far from the dairy and had a history of relatively light manure applications due to the inconvenience of hauling manure. In contrast, 2 (66%) of the 3 non-manured sites had PSNT values below 21 mg NO_3-N kg^{-1}. Forty-three percent of the manured sites had PSNT values > 45 mg NO_3-N kg^{-1}, which is more than double the critical concentration. While the shortage of N responsive sites made it difficult to calibrate the PSNT, the distribution of PSNT values is evidence of the need for improved N management on dairies and the potential for reduced fertilizer N inputs.

Table 7. Data for Cate-Nelson determination of Pre-sidedress Soil Nitrate Test (PSNT) critical value based on dry matter yield. Data are ranked in order of increasing PSNT values.

Site No.	PSNT (mg NO_3-N kg^{-1} soil)	0 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	200 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	Relative yield (%)
12	7	10.4	11.6	89.8
15	16	8.5	9.5	90.8
21	16	18.8	21.6	86.7
3	18	12.8	13.7	93.6
8	23	12.8	13.0	98.5
1	25	18.4	17.9	102.9
6	28	9.1	9.0	101.5
22	28	16.4	16.8	97.7
14	33	16.8	18.6	90.3
5	35	16.1	16.4	98.2
7	35	15.4	15.8	97.4
2	37	19.3	18.4	104.9
16	38	13.5	13.2	102.7
13	39	11.1	11.6	95.6
23	40	20.7	21.9	94.5
17	41	10.3	10.2	101.0
11	46	13.4	13.9	96.4
10	47	14.5	16.4	88.6
24	52	16.4	16.4	99.6
20	55	20.0	20.9	95.7
9	55	14.2	13.3	107.0
18	56	17.7	19.2	92.1
19	57	16.6	15.4	107.9
25	62	12.9	12.8	100.5
4	64	13.0	12.4	105.1
26	81	13.2	13.3	99.1

Table 8. Cate-Nelson analysis of Pre-sidedress Soil Nitrate Test (PSNT) and dry matter yield data.

Highest PSNT Value in Population 1	Mean Relative Yield Population 1	CSS-1[a]	Mean Relative Yield Population 2	CSS-2[b]	Postulated Critical Level	r^2 [†]
16	90.3	0.5	98.2	708.3	16	0.14
16	89.1	9.0	98.7	569.6	17	0.30
18	90.2	24.5	99.0	542.4	21 [‡]	0.31
23	91.9	79.3	99.0	542.1	24	0.25
25	93.7	180.5	98.8	526.1	27	0.14
28	94.8	232.4	98.7	518.5	28	0.09
28	95.2	239.6	98.7	517.5	31	0.08
33	94.6	260.4	99.2	443.3	34	0.15
35	95.0	271.7	99.3	442.2	35	0.14
35	95.2	276.9	99.4	438.5	36	0.13
37	96.0	362.9	99.0	405.9	38	0.07
38	96.5	404.3	98.7	391.0	39	0.04
39	96.5	405.1	99.0	380.3	39	0.05
40	96.3	408.7	99.4	358.7	40	0.07
41	96.6	429.4	99.2	355.6	43	0.05
46	96.6	429.4	99.5	347.0	47	0.06
47	96.2	490.0	100.9	213.2	50	0.15
52	96.4	501.2	101.1	211.3	53	0.14
55	96.3	501.5	102.0	178.1	55	0.18
55	96.8	610.7	100.9	147.1	55	0.08
56	96.6	631.9	103.1	49.9	57	0.17
57	97.1	754.1	101.5	19.4	60	0.06
62	97.3	765.1	102.1	17.8	63	0.05

N = 26; Total mean relative yield = 97.6; Total corrected sum of squares (TCSS) = 825.9.

[a] CSS-1 = corrected sum of squares of deviations from mean of population 1.

[b] CSS-2 = corrected sum of squares of deviations from mean of population 2.

[†] $r^2 = [TCSS - (CSS1 + CSS2)] / TCSS$

[‡] Postulated critical level with highest r^2-value is best separation of two populations.

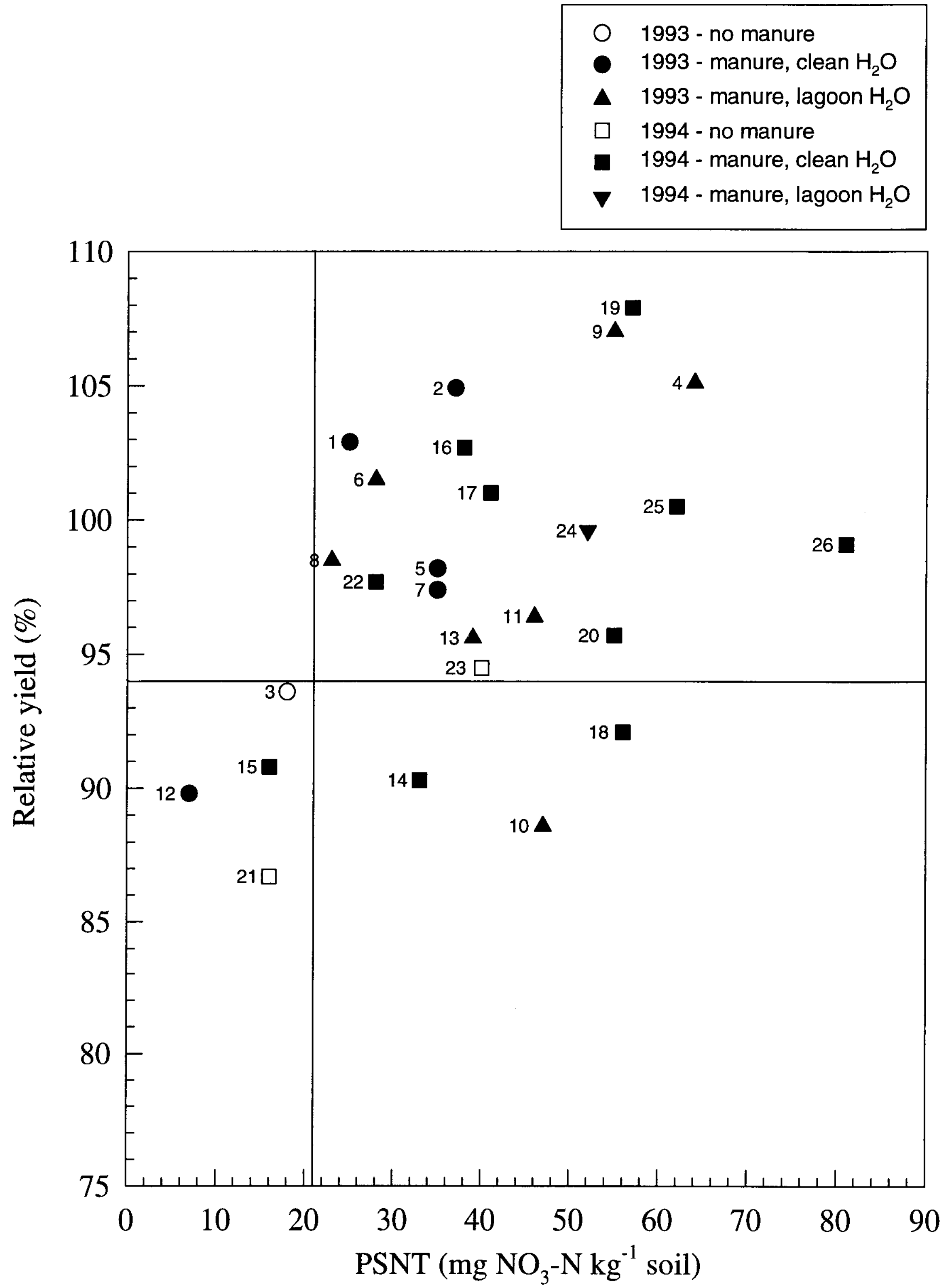

Fig. 2. Cate-Nelson plot of relative yield vs. Pre-sidedress Soil Nitrate Test (PSNT). Numbers are site numbers.

Though the PSNT error rate in this research was similar to many previous studies, the type of error was different. Two types of error are possible. Type I errors are represented by points falling in the upper left quadrant of the CN plot. Type I errors are sites where the PSNT predicted a yield response to N fertilization but no response was observed. In practice, Type I errors represent recommendations for unneeded fertilizer applications. Type II errors are represented by points falling in the lower right quadrant of the CN plot. Type II errors are sites where the PSNT predicted no response to N fertilization but a yield response was observed. Type II errors represent situations where a decision to forgo fertilization results in lost yield. In most previous studies, a majority of outliers were Type I errors. In this research, however, all outliers were Type II errors. Type II errors are considered of greater concern to growers, as the errors represent lost yield. Growers are assumed to be unlikely to use a soil test that does not consistently identify the potential for increased yields from N fertilization (Fox et al., 1992). Given current low N fertilizer costs and few governmental regulations regarding soil nutrients, this assumption may often be accurate. If N fertilizer costs or pressures for environmental protection increase, however, growers may be willing (or required) to be more conservative regarding N inputs. In such an environment, the risk of a small yield loss may be an acceptable alternative to application of potentially excessive N, and Type II errors may be of equal or less concern than Type I errors.

A brief analysis can put the economic risk of a Type II error in perspective. The yield reductions measured on Type II sites ranged from 1.9% to 5.4% below the acceptable 94% relative yield. Corn silage at 70% moisture is valued at $20/ton

(Miles, 1993). For a field yielding 22 tons silage/acre, a 5% yield reduction represents a loss of 1.1 tons of silage/acre worth $22. When evaluating long term risks from basing fertilizer inputs on the PSNT, the error rate must be considered. Suppose the PSNT makes a wrong prediction one out of five years. A $22/acre loss averaged over a five year period is equal to a $4.40/acre loss per year. This value is equivalent to 15 lb N/acre per year if N costs $0.30/lb. Therefore, if using the PSNT can reduce fertilizer inputs by more than 15 lb N/year over a five year period, an economic advantage is likely even with an incorrect prediction in one out of five years. Data from this research indicate that many dairies exceed N fertilization requirements by 100 lb N/acre/year or more, implying an economic benefit to be gained from adoption of management tools such as the PSNT. While this analysis shows a favorable risk/benefit situation, grower perception might be otherwise and resistance to adoption of new management practices may be encountered.

Sites 14 and 18 were Type II errors in 1994. Both sites had maximum DM yields over 18.5 Mg ha^{-1}, ranking them among the most productive sites in the study. More nitrogen may be needed to realize maximum yield on highly productive sites as compared to less productive sites. Therefore, analysis of soil NO_3-N per unit yield may improve predictions of N responsiveness. Magdoff et al. (1984) reported a yield adjusted PSNT critical value of 3.1 kg NO_3-N Mg^{-1} yield. By including yield potential in analysis, Magdoff et al.'s Type II error rate was reduced from 9% to 5%, while the Type I error rate remained at 2%. With further research, a critical value of approximately 8.25 kg NO_3-N Mg^{-1} yield (1.84 mg NO_3-N kg^{-1} soil Mg^{-1} yield) was determined (Fred Magdoff, personal communication).

Yield adjusted PSNT values and relative yield data are presented in Table 9. CN analysis determined a yield adjusted PSNT critical value of 12.3 kg NO_3-N Mg^{-1} yield (Table 9), which is somewhat higher than the value reported by Magdoff et al. All Type II errors were eliminated by yield adjustment (Fig. 3). However, yield adjusted analysis resulted in a 35% Type I error rate, suggesting that yield adjustment does not improve the ability of the PSNT to separate N responsive and non-responsive sites. Using Magdoff's critical value of 8.25 kg NO_3-N Mg^{-1} yield instead of the calculated value reduces the error rate to 23%. In other words, while CN analysis calculated a point of separation for two populations, it did not determine the critical value with the lowest possible error rate. The small, poorly distributed data set may have contributed to the failure of CN analysis to determine the best critical value. From this research, the 21 mg NO_3-N kg^{-1} soil PSNT critical value appears to be better than yield based calculations as a predictor of N response.

The data suggest that the PSNT may be used with as much confidence in western Oregon as in the eastern United States. In eastern regions, adoption of the PSNT method has been slow due to the inconvenience of midseason soil testing (Magdoff, et al., 1990). Similar resistance to the PSNT method can be expected in Oregon. Presently, many silage corn producers make all fertilizer management decisions in the spring. Some producers split fertilizer applications between planting and midseason sidedressing. Other growers apply all fertilizer before or at planting to avoid the inconvenience of midseason sidedressing. For growers applying all fertilizer before or at planting, once the seed is in the ground the crop can virtually

Table 9. Data for Cate-Nelson determination of yield adjusted Pre-sidedress Soil Nitrate Test (PSNT) critical value based on dry matter yield. Data are ranked in order of increasing PSNT values.

Site No.	PSNT (kg NO_3-N Mg^{-1} yield)	0 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	200 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	Relative yield (%)
12	2.5	10.4	11.6	89.8
21	3.1	18.8	21.6	86.7
3	5.4	12.8	13.7	93.6
1	5.7	18.4	17.9	102.9
22	6.9	16.4	16.8	97.7
15	7.0	8.6	9.5	90.8
8	7.2	12.8	13.0	98.5
14	7.3	16.8	18.6	90.3
23	7.4	20.7	21.9	94.5
2	8.2	19.3	18.4	104.9
5	8.7	16.1	16.4	98.2
7	9.1	15.4	15.8	97.4
20	10.7	20.0	20.9	95.7
10	11.7	14.5	16.4	88.6
16	11.8	13.5	13.2	102.7
18	11.8	17.7	19.2	92.1
6	12.7	9.1	9.0	101.5
24	13.0	16.4	16.4	99.6
11	13.5	13.4	13.9	96.4
13	13.7	11.1	11.6	95.6
19	15.3	16.6	15.4	107.9
17	16.3	10.3	10.2	101.0
9	16.9	14.2	13.3	107.0
25	19.8	12.9	12.8	100.5
4	21.1	13.0	12.4	105.1
26	24.9	13.2	13.3	99.1

Table 10. Cate-Nelson analysis of yield adjusted Pre-sidedress Soil Nitrate Test (PSNT) and dry matter yield data.

Highest Adj. PSNT Value in Population 1	Mean Relative Yield Population 1	CSS-1[a]	Mean Relative Yield Population 2	CSS-2[b]	Postulated Critical Level	r^2 [†]
3.1	88.2	4.7	98.4	630.4	4.2	0.23
5.4	90.0	24.1	98.6	606.6	5.5	0.24
5.7	93.3	148.1	98.4	587.4	6.3	0.11
6.9	94.1	163.9	98.5	586.9	6.9	0.09
7.0	93.6	173.3	98.8	524.9	7.1	0.15
7.2	94.3	194.0	98.9	524.8	7.3	0.13
7.3	93.8	207.6	99.3	448.3	7.3	0.21
7.4	93.9	208.1	99.6	423.8	7.8	0.23
8.2	95.0	317.6	99.3	394.1	8.5	0.14
8.7	95.3	327.0	99.4	392.8	8.9	0.13
9.1	95.4	331.2	99.5	388.7	9.9	0.13
10.7	95.5	331.2	99.8	373.4	11.2	0.15
11.7	95.0	374.8	100.7	238.2	11.8	0.26
11.8	95.5	430.8	100.5	233.8	11.8	0.20
11.8	95.3	441.4	101.4	156.0	12.3 [‡]	0.28
12.7	95.6	477.8	101.4	156.0	12.9	0.23
13.0	95.9	492.6	101.6	152.5	13.3	0.22
13.5	95.9	492.9	102.3	122.1	13.6	0.26
13.7	95.9	493.0	103.4	68.9	14.5	0.32
15.3	96.5	631.2	102.5	44.8	15.8	0.18
16.3	96.7	651.3	102.9	42.0	16.6	0.16
16.9	97.1	754.1	101.5	19.4	18.4	0.06
19.8	97.3	765.1	102.1	17.8	20.5	0.05

N = 26; Total mean relative yield = 97.6; Total corrected sum of squares (TCSS) = 825.9.

[a] CSS-1 = corrected sum of squares of deviations from mean of population 1.

[b] CSS-2 = corrected sum of squares of deviations from mean of population 2.

[†] r^2 = [TCSS - (CSS-1 + CSS2)] / TCSS

[‡] Postulated critical level with highest r^2-value is best separation of two populations.

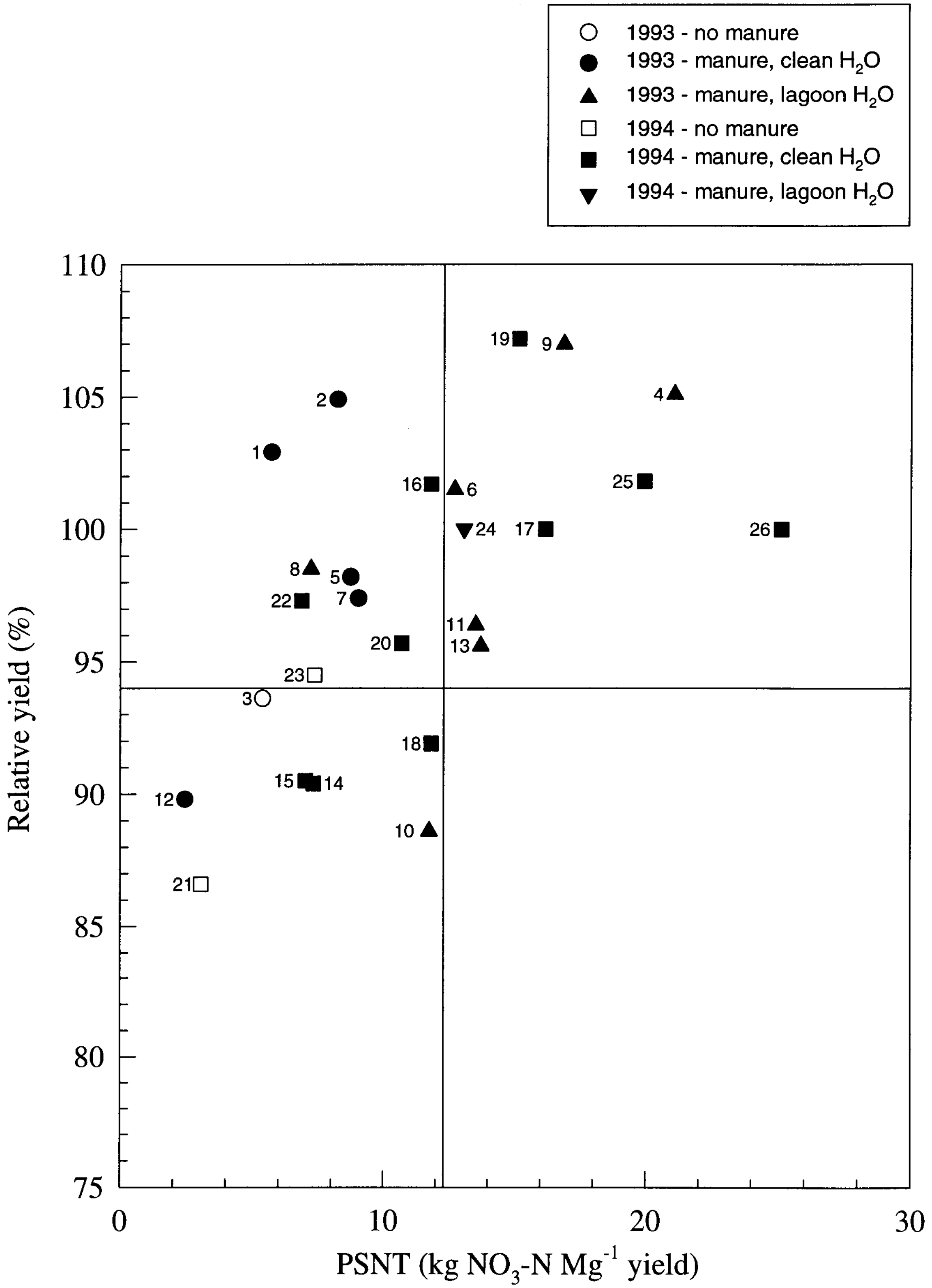

Fig. 3. Cate-Nelson plot of relative yield vs. yield adjusted Pre-sidedress Soil Nitrate Test (PSNT). Numbers are site numbers.

ignored with the exception of irrigation. This management approach allows the dairy producer to concentrate on tasks other than corn production during the summer months.

The PSNT requires a different approach to fertility management for corn. For the PSNT to be used effectively, fertilization decisions must be delayed until midseason. In addition to delayed decision making, a midseason soil sample must be collected and analyzed. Though data suggest the method can result in significant economic savings for the producer, old habits may be hard to break. Methods for identifying N responsive and non-responsive sites at an earlier date may be more readily adopted by growers. Two early season methods were evaluated in this study: soil nitrate at planting (SNAP), and 205 nm absorption of 0.01M $NaHCO_3$ extract (UV205) from soil samples taken from 0 to 30 cm at planting.

Soil nitrate at planting

The SNAP method is identical to the PSNT method with the exception that soil testing occurs at planting instead of at the V5/V6 growth stage. SNAP values ranged from 4 to 80 mg NO_3-N kg^{-1} (Table 11), and tended to be lower than PSNT values. This trend was expected, due to N mineralization occurring between SNAP and PSNT sampling.

To calibrate a nitrogen soil test, N inputs must be eliminated after collection of the test sample. N applied after sampling makes it impossible to determine the sufficiency of the soil N supply at the time of testing. In this study, manure lagoon water applied during irrigation contained considerable amounts of N, confounding analysis of the sufficiency of the soil nitrate supply at planting. Therefore, sites receiving manure lagoon irrigation water were excluded from SNAP analysis.

CN analysis determined a SNAP critical value of 22 mg NO_3-N kg^{-1} with a 28% error rate (Table 12, Fig. 4). The PSNT error rate for non-lagoon sites was 11%. Sites 14 and 18 were Type II errors in both tests.

The SNAP test incorrectly predicted sites 1, 5, and 22 to be N responsive. During the period between SNAP sampling and PSNT sampling, soil NO_3-N concentrations at sites 1, 5, and 22 increased by 10, 15, and 17 mg NO_3-N kg^{-1}, respectively, presumably due to N mineralization. The PSNT reflected this early season N mineralization because of the later sampling date, and all three sites were correctly identified as N non-responsive by the PSNT.

The SNAP critical value of 22 mg NO_3-N kg^{-1} is similar to the PSNT critical value of 21 mg NO_3-N kg^{-1}. Soil nitrate levels are unlikely to decrease during the early growing season unless excessive irrigation results in leaching or addition of organic matter with a high C:N ratio results in microbial immobilization. Therefore, if soil NO_3-N concentrations are above 21 mg NO_3-N kg^{-1} at planting, there is a high probability that concentrations will be above 21 mg NO_3-N kg^{-1} at PSNT, as well. The similarity of the SNAP and PSNT critical values suggests that the SNAP test is merely operating as an early PSNT on sites with high soil nitrate levels.

The high percentage of dairy sites testing above the SNAP critical value implies the test may be of use for making earlier N management decisions in some situations. If the SNAP test is below 22 mg NO_3-N kg^{-1}, prediction of N responsiveness is uncertain and a second test should be performed at PSNT. While

Table 11. Data for Cate-Nelson determination of critical value for soil nitrate at planting (SNAP) based on dry matter yield. Lagoon irrigated sites are excluded. Data are ranked in order of increasing SNAP values.

Site No.	SNAP (mg NO_3-N kg^{-1} soil)	0 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	200 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	Relative Yield (%)
22	11	16.4	16.8	97.7
12	11	10.4	11.6	89.8
15	13	8.6	9.5	90.8
3	15	12.8	13.7	93.6
1	15	18.4	17.9	102.9
5	20	16.1	16.4	98.2
21	20	18.8	21.6	86.7
16	24	13.5	13.2	102.7
17	25	10.3	10.2	101.0
14	29	16.8	18.6	90.3
7	29	15.4	15.8	97.4
23	30	20.7	21.9	94.5
19	36	16.6	15.4	107.9
25	40	12.9	12.8	100.5
18	41	17.7	19.2	92.1
26	63	13.2	13.3	99.1
2	67	19.3	18.4	104.9
20	80	20.0	20.9	95.7

Table 12. Cate-Nelson analysis of soil nitrate at planting (SNAP) and dry matter yield data.

Highest SNAP Value in Population 1	Mean Relative Yield Population 1	CSS-1[a]	Mean Relative Yield Population 2	CSS-2[b]	Postulated Critical Level	r^2 †
11	93.7	31.3	97.4	513.2	12	0.04
13	92.7	37.1	97.8	466.2	14	0.11
15	93.0	37.7	98.1	447.2	15	0.15
15	95.0	116.6	97.8	422.9	17	0.05
20	95.5	125.4	97.7	422.8	20	0.04
20	94.2	191.6	98.8	289.7	22 ‡	0.15
24	95.3	254.5	98.4	272.4	25	0.07
25	95.9	283.8	98.1	264.4	27	0.04
29	95.4	312.0	99.0	197.4	29	0.10
29	95.6	315.6	99.3	194.4	29	0.10
30	95.5	316.6	100.0	168.2	33	0.15
36	96.4	459.7	98.5	93.7	38	0.03
40	96.7	475.1	98.0	88.6	40	0.01
41	96.4	494.8	99.9	43.1	52	0.05
63	96.6	501.6	100.3	42.1	65	0.04

N = 18; Total mean relative yield = 97.0; Total corrected sum of squares (TCSS) = 568.4.

[a] CSS-1 = corrected sum of squares of deviations from mean of population 1.
[b] CSS-2 = corrected sum of squares of deviations from mean of population 2.
† r^2 = [TCSS - (CSS-1 + CSS2)] / TCSS
‡ Postulated critical level with highest r^2-value is best separation of two populations.

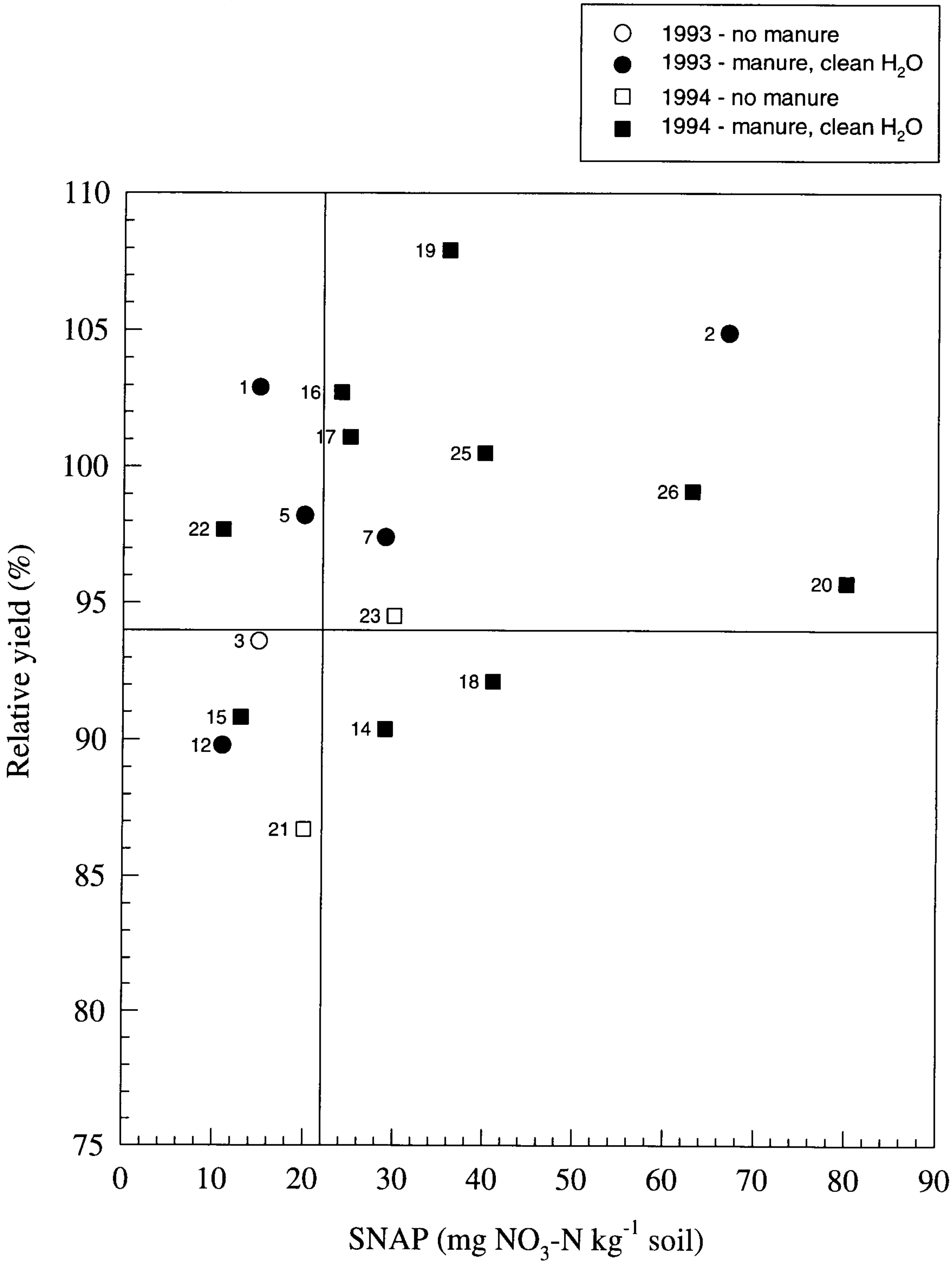

Fig. 4. Cate-Nelson plot of relative yield vs. soil nitrate at planting (SNAP). Numbers are site numbers.

the prospect of having to perform soil nitrate tests twice in one season may seem discouraging, the development of quick-test field kits may make testing routine. The advantages of early identification of N sufficiency may balance the prospect of repeated soil testing for some growers.

UV205 method

The 200 nm absorbance of 0.01*M* $NaHCO_3$ extract from soil samples collected at planting (UV200 method) is hypothesized to indicate the nitrogen supplying capability of soil (Hong et al., 1990). Like the SNAP, the UV200 method has the advantage of early soil sampling. The UV200 method is hypothesized to have the added advantage of indicating potential N mineralization. We did not become aware of the method until part way through our study, and our evaluation of the method was cursory. Results are included in this report as a basis for further study. Absorbance at 205 nm was measured because absorbance readings were more stable than at 200 nm.

Samples from sites receiving lagoon irrigation water were not included in UV205 analysis due to the additional N applied in the water. Cate-Nelson analysis determined a critical value of 2.05 absorbance units (Tables 13, 14). The error rate for the UV205 method was 17% (Fig. 5). Fox et al. (1992) reported a 200 nm absorbance critical value of 1.51 absorbance units with a 21% error rate. The UV205 method was successful at identifying 5 of 6 N responsive sites. Site 18, the only Type II error, was also a Type II error in PSNT analysis. UV205 absorbance was highly correlated ($r^2 = 0.89$) with soil NO_3-N, suggesting that absorbance was strongly influenced by the NO_3-N concentration in the extract.

Table 13. Data for Cate-Nelson determination of critical value for 205 nm absorbance (UV205) of 0.01*M* $NaHCO_3$ extract from soil samples collected at planting based on dry matter yield. Lagoon irrigated sites are excluded. Data are ranked in order of increasing UV205 values.

Site No.	UV205 (absorbance units)	0 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	200 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	Relative Yield (%)
22	1.16	16.4	16.8	97.7
21	1.39	18.8	21.6	86.7
12	1.43	10.4	11.6	89.8
3	1.52	12.8	13.7	93.6
15	1.72	8.6	9.5	90.8
5	1.94	16.1	16.4	98.2
14	2.00	16.8	18.6	90.3
1	2.10	18.4	17.9	102.9
16	2.27	13.5	13.2	102.7
17	2.32	10.3	10.2	101.0
7	2.36	15.4	15.8	97.4
19	2.41	16.6	15.4	107.9
23	2.53	20.7	21.9	94.5
25	2.80	12.9	12.8	100.5
18	3.40	17.7	19.2	92.1
2	3.90	19.3	18.4	104.9
20	4.00	20.0	20.9	95.7
26	4.00	13.2	13.3	99.1

Table 14. Cate-Nelson analysis of UV205 and dry matter yield data.

Highest UV205 Value in Population 1	Mean Relative Yield Population 1	CSS-1[a]	Mean Relative Yield Population 2	CSS-2[b]	Postulated Critical Level	r^2 †
1.39	92.2	60.3	97.6	451.7	1.41	0.09
1.43	91.4	64.2	98.1	386.0	1.48	0.20
1.52	91.9	67.9	98.5	363.8	1.62	0.23
1.72	91.8	68.4	99.0	305.7	1.83	0.34
1.94	92.8	102.8	99.1	305.0	1.97	0.28
2.00	92.5	108.1	99.9	221.8	2.05 ‡	0.42
2.10	93.8	202.8	99.6	211.9	2.19	0.27
2.27	94.8	273.5	99.3	201.1	2.30	0.16
2.32	95.4	309.2	99.0	197.3	2.34	0.10
2.36	95.6	312.7	99.3	194.3	2.39	0.10
2.41	96.6	452.0	97.8	106.6	2.47	0.01
2.53	96.5	456.1	98.5	93.7	2.67	0.03
2.80	96.7	471.2	98.0	88.5	3.10	0.01
3.40	96.4	491.2	99.9	43.1	3.65	0.05
3.90	97.0	558.3	97.4	5.7	3.95	0.00

N = 18; Total mean relative yield = 97.0; Total corrected sum of squares (TCSS) = 568.4.

[a] CSS-1 = corrected sum of squares of deviations from mean of population 1.

[b] CSS-2 = corrected sum of squares of deviations from mean of population 2.

† r^2 = [TCSS - (CSS-1 + CSS2)] / TCSS

‡ Postulated critical level with highest r^2-value is best separation of two populations.

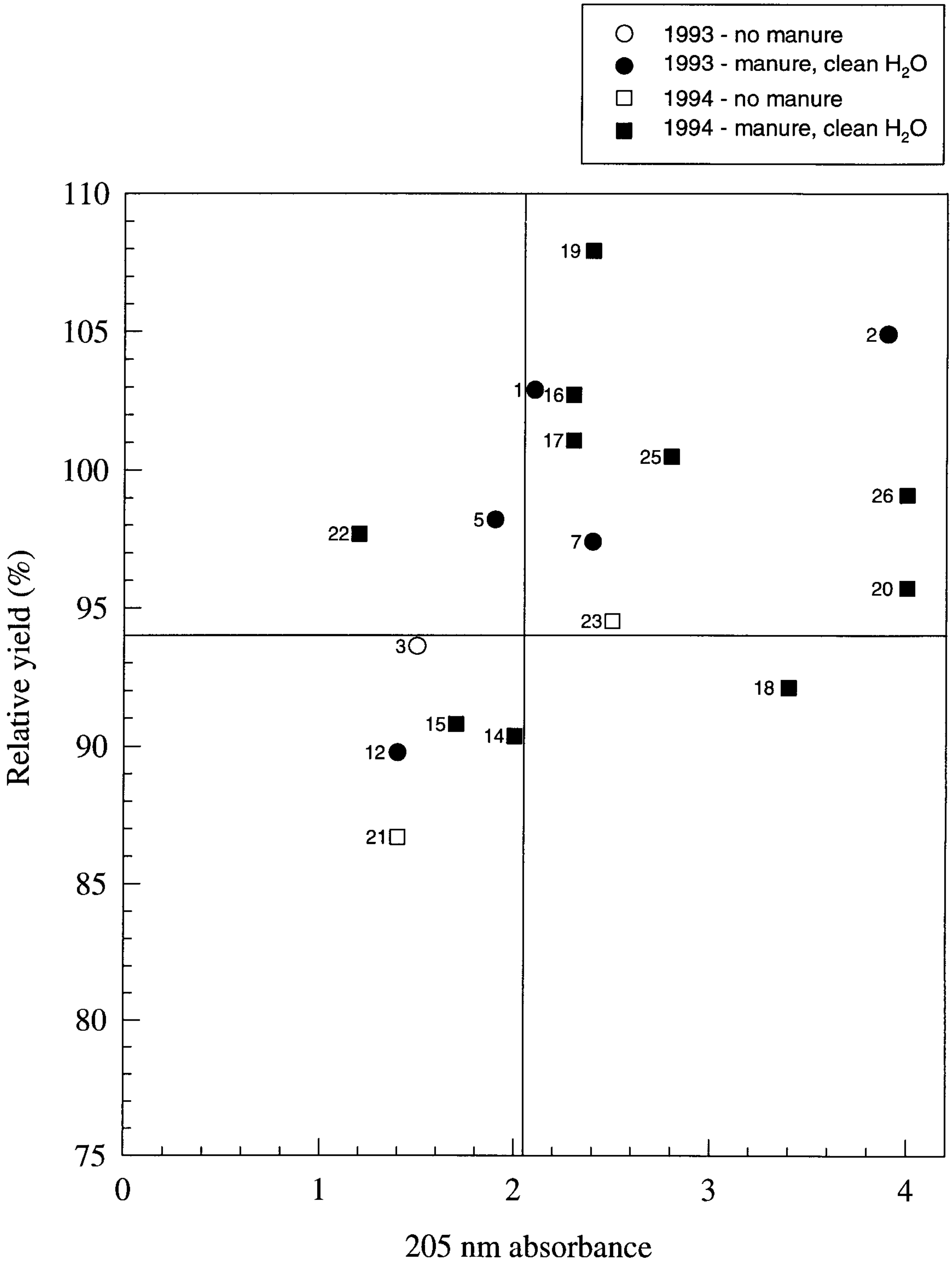

Fig. 5. Cate-Nelson plot of relative yield vs. 205 nm absorbance of 0.01*M* $NaHCO_3$ soil extract. Numbers are site numbers.

Though the same soil samples were analyzed, the UV205 method, with a 17% error rate, was a better predictor of N responsiveness than the SNAP test, which had a 28% error rate. Both the SNAP and UV205 methods, however, were unable to predict the N non-responsiveness of sites 5 and 22. As discussed previously, early season N mineralization resulted in the failure of the SNAP to identify N non-responsiveness while the PSNT succeeded. The UV205 method, however, is hypothesized to predict N supplying capability by measuring both NO_3-N and solubilized organic matter (Hong et al., 1990). Failure of the UV205 method to identify sites 5 and 22 as N non-responsive raises questions regarding the method's ability to correct for sites with large pools of mineralizable N.

Problems existed in the reproducibility of 205 nm absorbance data. The data presented above was from the first of two lab runs. A subsequent lab run involving 24 samples resulted in variation from the original analysis (Fig. 6). Three samples that tested above the 2.05 AU critical value in run 1 were below 2.05 AU in run 2. This is of concern, as the recommendation for or against additional N applications would be different based on the two test values.

Problems with data reproducibility were further evidenced by variation among duplicated soil samples. One duplicated sample had absorbance values of 1.75 and 1.79 in run 1, and values of 1.66 and 1.41 in run 2. A second duplicated sample had absorbance values of 2.49 and 2.83 in run 1 and 2.30 and 2.40 in run 2. While recommendations would not be affected by these differences, the differences were great enough to raise concern regarding the validity of test values.

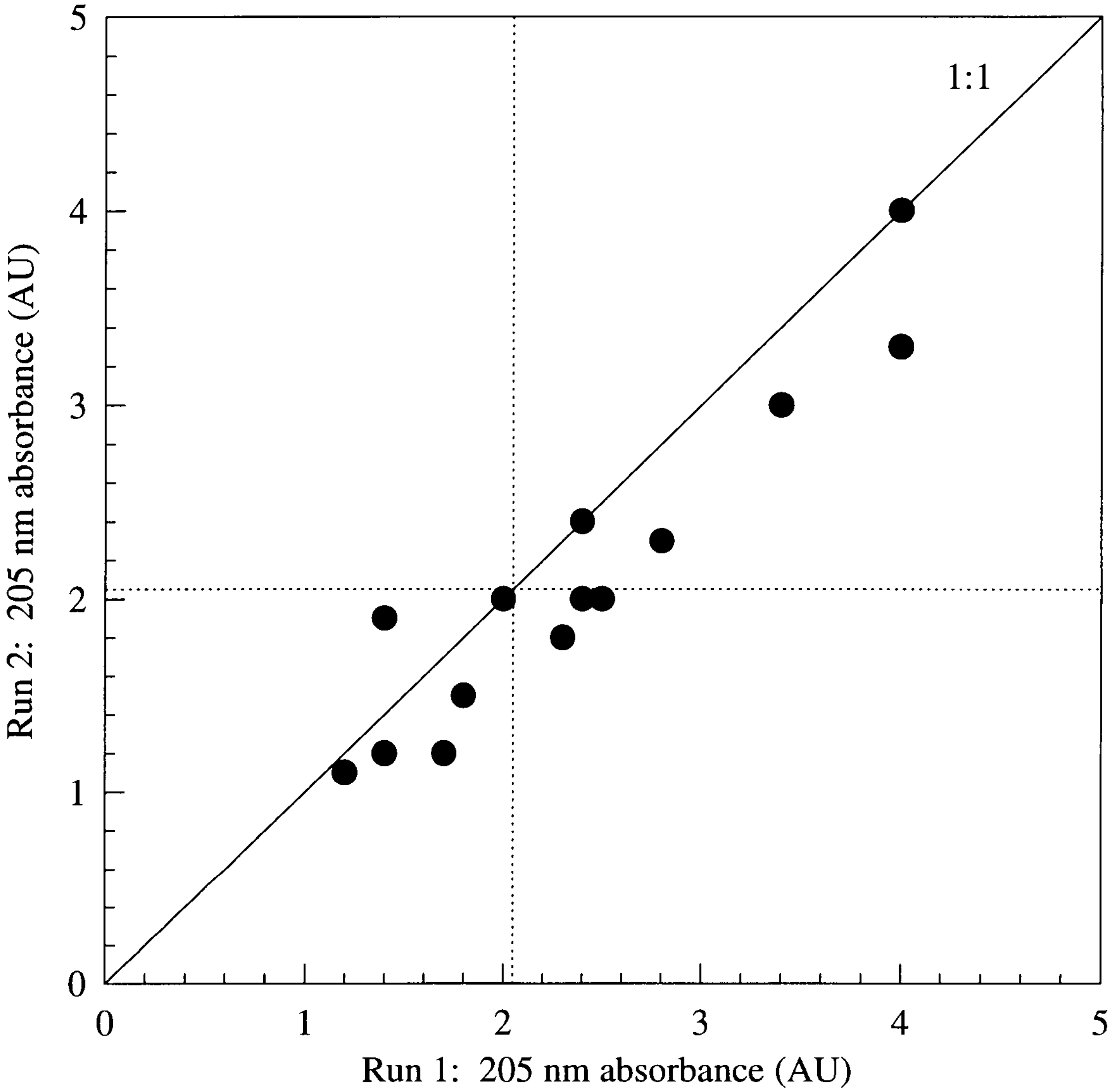

Fig. 6 Comparison of UV205 data from two lab runs. Dotted lines indicate critical value of 2.05 AU determined by analysis of data from run 1.

Interference from the $NaHCO_3$ matrix is a possible source of error. The extracts were acidified with HCl to eliminate HCO_3^-, which absorbs at 205 nm. The effects of HCO_3^- and acidification on 205 nm absorbance can be seen in standard curves (Fig. 7). Nitrate standards were prepared in H_2O, 0.01*M* $NaHCO_3$, and 0.01*M* $NaHCO_3$ acidified with 100µL of concentrated HCl. For each curve, the reference cell contained blank matrix solution. The curves were linear and had similar slopes for nitrate concentrations ≤ 2.0 mg mL^{-1} in all three matrices (Table 15). Absorbance due to nitrate, however, was reduced by about 0.56 AU when prepared in 0.01*M* $NaHCO_3$. Following acidification to eliminate HCO_3^-, the reduction in absorbance due to nitrate was about 0.20 AU. The negative y-intercepts are unexplained.

Table 15. UV205 standards curve equations and coefficients of determination (r^2) for nitrate standards ≤ 2.0 mg mL^{-1}.

	Matrix		
	H_2O	0.01*M* $NaHCO_3$ (no HCl)	0.01*M* $NaHCO_3$ (+ HCl)
r^2	0.9984	0.9989	0.9938
equation	NO_3-N=0.603(UV205)-0.0155	NO_3-N=0.617(UV205)-0.5765	NO_3-N=0.521(UV205)-0.2199

Acidification with HCl may, itself, introduce error, as evidenced by an increase of 0.27 absorbance units when blank H_2O was acidified. Cawse (1967) identified Cl^- as a source of interference at 203 nm. Modifying the procedure to use H_2SO_4 in place of HCl may correct the problem.

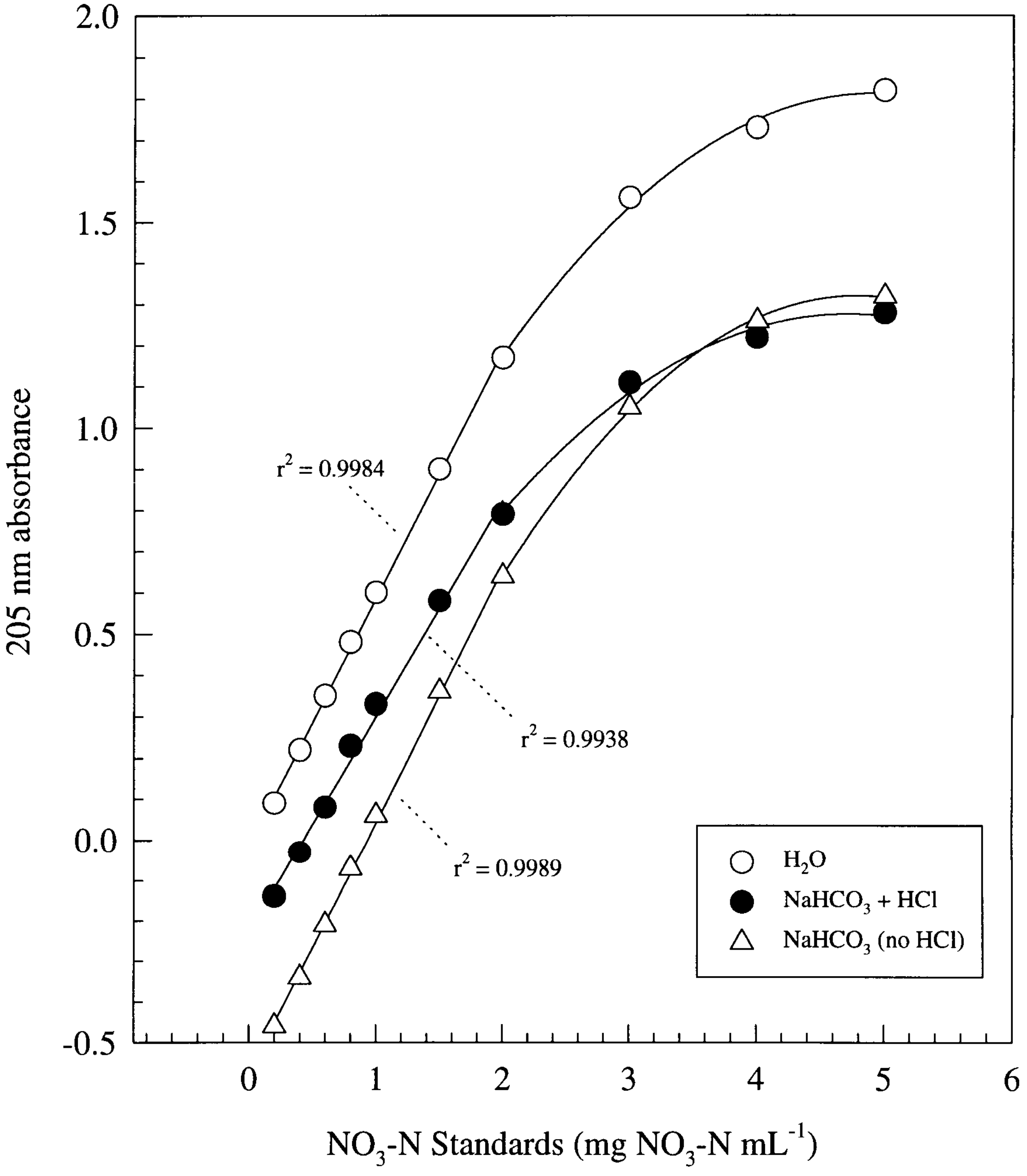

Fig. 7. Absorbance at 205 nm of NO_3-N standards prepared in H2O, .01*M* $NaHCO_3$, and .01*M* $NaHCO_3$ acidified with HCl. The reference cell for each curve contained blank matrix solution. Coefficients of determination are for standards < or = 2.0 mg mL^{-1}.

Another potential source of error is the filter paper. Passing blank $NaHCO_3$ through Whatman no. 42 filter paper resulted in an increase of 0.15 absorbance units. The increase may be greater when filtering soil extracts, as the slower filtration rate results in increased contact between $NaHCO_3$ and the filter paper. Richard H. Fox has also noted increases in absorption caused by filter paper (personal communication). An alternative method of recovering the soil extract, such as centrifuging, would eliminate this source of error.

Because HCO_3^- is a potential source of error, further modification of the method to avoid use of $NaHCO_3$ is worth considering. $NaHCO_3$ extracts easily solubilized organic matter, which was found to correlate with soil nitrogen supplying capability (MacLean, 1964; Fox et al., 1978a). Keeney & Bremner (1966) found that using boiling water to extract soluble organic matter, followed by Kjeldahl digestion, was also an effective method for estimating soil N availability. Modifying the Keeney & Bremner method by measuring 210 nm absorbance of the boiling water extract instead of performing Kjeldahl analysis may be an effective approach for estimating soil N supplying capability. This proposed modification of the Keeney & Bremner method is essentially the same modification Hong et al. (1990) made to the method of MacLean (1964). The absorbance at 210 nm instead of 205 nm is suggested because Cawse (1967) reported decreased interference from non-nitrate species at the higher wavelength.

Plant nitrogen concentration

Soil N supply may affect not only dry matter yield, but also the N concentration in the harvested plant. Plant N concentration can be an indicator of protein concentration, which is a feed quality parameter of interest to dairy producers. Corn silage is generally valued as a high energy forage, however, and protein concentrations are of secondary importance. If protein concentration increases substantially with added N after DM yields are maximized, then basing fertilization decisions solely on DM yield data may be inappropriate.

Total Kjeldahl Nitrogen (TKN) increased significantly ($P < .05$) with added N fertilizer on all sites with PSNT values below the 21 mg NO_3-N kg^{-1} critical value (Table 16). Of the 22 sites with PSNT values above 21 mg NO_3-N kg^{-1}, only four showed a TKN increase with added N fertilizer. The data suggest that soil N supplies sufficient to maximize dry matter yield are also sufficient to maximize plant TKN concentrations.

Cate-Nelson analysis of percent relative TKN data determined a PSNT critical value of 21 mg NO_3-N kg^{-1} (Tables 17, 18). This is the same PSNT critical value determined for optimizing DM yield. A 90% relative TKN sufficiency level was justified by the secondary importance of protein as a yield parameter. The CN plot shows three Type II errors, resulting in an 12% error rate (Fig. 8). Type II errors were sites where the PSNT predicted no TKN response to N fertilization but an increase in TKN was observed. When N was applied to sites that were N non-responsive with respect to DM, the largest TKN increase was 0.17%, which is equivalent to a 1.1% increase in protein. In summary, TKN is expected to increase with added N when PSNT values are below 21 mg NO_3-N kg^{-1}, while smaller TKN

Table 16. T-test analysis of plant Total Kjeldahl Nitrogen (TKN) concentration data. Sites are listed in order of increasing PSNT values (mg NO_3-N kg^{-1} soil). Dotted line separates sites above and below PSNT critical value of 21 mg NO_3-N kg^{-1} soil. *, ** Significant difference between treatments at $P < 0.05$, 0.01, respectively.

Site No.	PSNT	mean TKN (%)		C.V.	T-test
	(mg NO_3-N kg^{-1})	0 kg N ha^{-1}	200 kg N ha^{-1}	(%)	P-value
12	7	0.88	1.12	5.8	0.00 **
15	16	1.16	1.35	6.9	0.02 *
21	16	0.92	1.11	8.1	0.01 **
3	18	0.96	1.08	4.4	0.01 **
8	23	1.22	1.29	7.3	0.34
1	25	1.11	1.11	6.6	0.96
6	28	1.23	1.40	7.1	0.04 *
22	28	1.19	1.25	5.6	0.28
14	33	1.20	1.30	5.8	0.10
5	35	1.08	1.16	9.6	0.34
7	35	1.15	1.20	5.7	0.40
2	37	1.10	1.15	9.9	0.57
16	38	1.38	1.45	5.9	0.33
13	39	1.73	1.65	9.4	0.53
23	40	1.13	1.29	9.2	0.09
17	41	1.37	1.41	3.6	0.31
11	46	1.42	1.55	3.9	0.04 *
10	47	1.48	1.45	3.3	0.37
24	52	1.48	1.49	4.3	0.83
20	55	1.19	1.34	4.3	0.01 **
9	55	1.31	1.35	7.6	0.62
18	56	1.14	1.19	7.3	0.49
19	57	1.28	1.42	4.0	0.01 **
25	62	1.62	1.72	10.3	0.44
4	64	1.41	1.49	4.3	0.11
26	81	1.67	1.65	5.7	0.80

Table 17. Data for Cate-Nelson determination of PSNT critical value based on plant Total Kjeldahl Nitrogen (TKN). Data are ranked in order of increasing PSNT values.

Site No.	PSNT (mg NO_3-N kg^{-1} soil)	0 kg N ha^{-1} treatment TKN (%)	200 kg N ha^{-1} treatment TKN (%)	Relative TKN (%)
12	7	0.88	1.12	78.6
15	16	1.16	1.35	85.9
21	16	0.92	1.11	82.9
3	18	0.96	1.08	88.2
8	23	1.22	1.29	94.6
1	25	1.11	1.11	100.0
6	28	1.23	1.40	87.4
22	28	1.19	1.25	95.2
14	33	1.20	1.30	92.3
5	35	1.08	1.16	93.1
7	35	1.15	1.20	95.8
2	37	1.10	1.15	95.7
16	38	1.38	1.45	95.2
13	39	1.73	1.65	104.8
23	40	1.13	1.29	87.6
17	41	1.37	1.41	97.2
11	46	1.42	1.55	91.5
10	47	1.48	1.45	102.1
24	52	1.48	1.49	99.3
20	55	1.19	1.34	88.8
9	55	1.31	1.35	97.0
18	56	1.14	1.19	95.8
19	57	1.28	1.42	90.1
25	62	1.62	1.72	94.2
4	64	1.41	1.49	94.6
26	81	1.67	1.65	101.2

Table 18. Cate-Nelson analysis of Pre-sidedress Soil Nitrate Test (PSNT) and Total Kjeldahl nitrogen (TKN) data.

Highest PSNT Value in Population 1	Mean Relative TKN Population 1	CSS-1[a]	Mean Relative TKN Population 2	CSS-2[b]	Postulated Critical Level	r^2 [†]
16	82.2	27.0	94.4	622.0	16	0.29
16	82.5	27.3	94.9	484.5	17	0.44
18	83.9	52.3	95.2	438.7	21 [‡]	0.47
23	86.0	143.4	95.2	438.3	24	0.37
25	88.4	305.9	94.9	414.0	27	0.22
28	88.2	306.7	95.3	353.4	28	0.28
28	89.1	349.3	95.4	353.4	31	0.24
33	89.5	358.5	95.5	343.5	34	0.24
35	89.8	370.5	95.7	337.3	35	0.23
35	90.4	403.5	95.7	337.2	36	0.19
37	90.8	429.1	95.7	337.2	38	0.17
38	91.1	446.7	95.7	337.0	39	0.15
39	92.1	621.2	95.0	246.6	39	0.06
40	91.8	640.3	95.6	187.5	40	0.10
41	92.2	667.1	95.5	184.9	43	0.07
46	92.1	667.5	95.9	167.4	47	0.09
47	92.7	761.1	95.1	124.7	50	0.04
52	93.0	803.2	94.5	104.7	53	0.01
55	92.8	820.0	95.5	66.3	55	0.04
55	93.0	837.1	95.2	63.5	55	0.02
56	93.1	844.5	95.0	63.0	57	0.01
57	93.0	853.1	96.7	31.0	60	0.04
62	93.1	854.4	97.9	21.7	63	0.05

N = 26; Total mean relative yield = 93.4; Total corrected sum of squares (TCSS) = 919.8.

[a] CSS-1 = corrected sum of squares of deviations from mean of population 1.

[b] CSS-2 = corrected sum of squares of deviations from mean of population 2.

[†] r^2 = [TCSS - (CSS-1 + CSS2)] / TCSS

[‡] Postulated critical level with highest r^2-value is best separation of two populations.

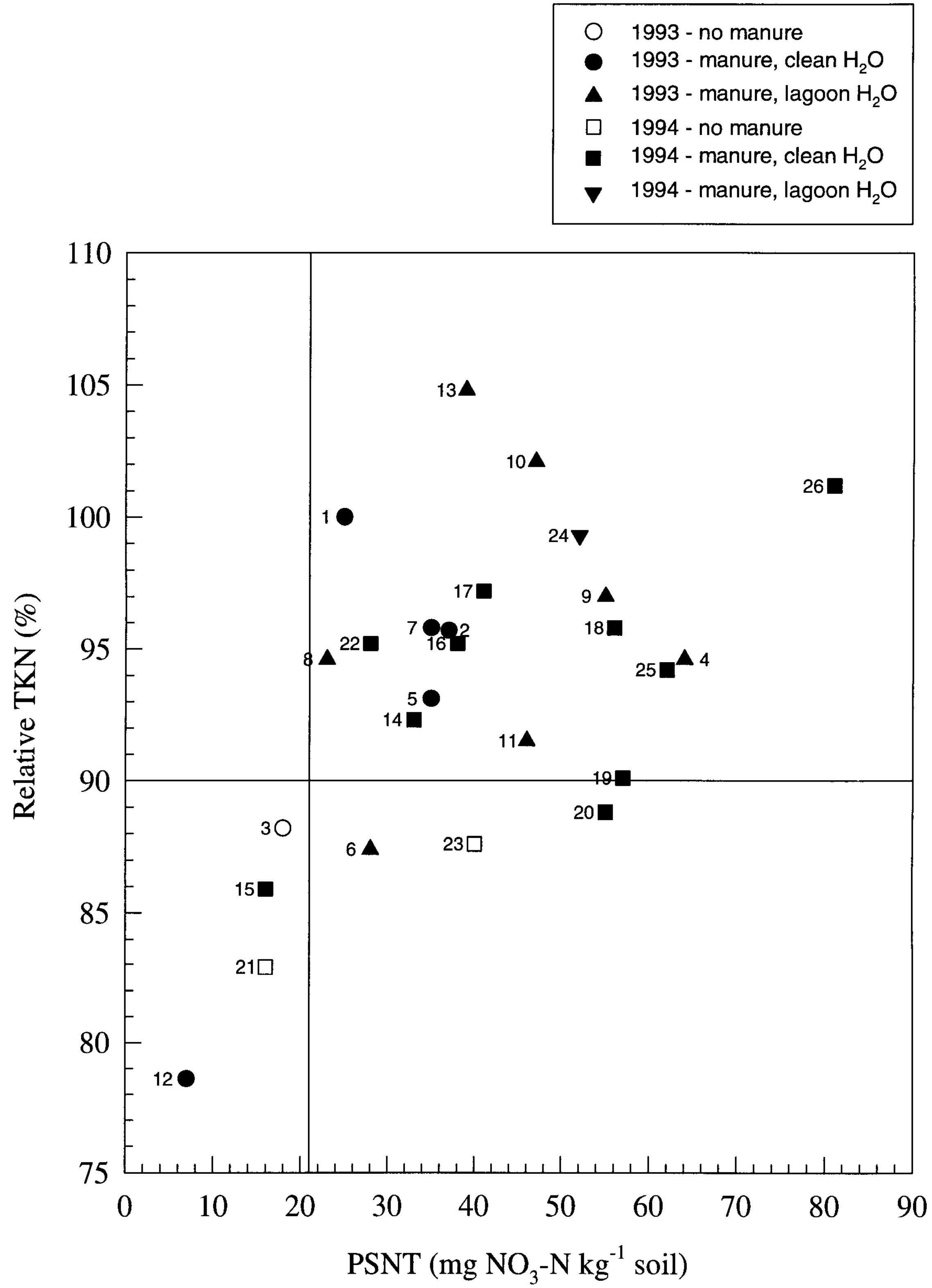

Fig. 8. Cate-Nelson plot of relative plant Total Kjeldahl Nitrogen (TKN) vs. Pre-sidedress Soil Nitrate Test (PSNT). Numbers are site numbers.

increases of little practical significance may or may not occur at higher soil N concentrations.

Nitrogen removed in crop

Growers attempting to balance a whole farm nutrient budget by cycling nitrogen through forage crops need to know how much nitrogen a crop can remove from the soil. Crop N removal potential may be an important factor in crop selection.

Crop N removal data is shown in Table 19. Crop N removal potential ranged from 126 to 283 kg N ha^{-1}. Differences among sites were largely a function of differences in yield potential. Corn hybrid differences may also play a role. There was a trend of higher crop N removal on sites irrigated with lagoon water. This trend may be explained by contamination of plant samples by manure residues.

Five sites showed a significant ($P < .05$) increase in N removed ha^{-1} when additional N fertilizer was applied. Only one site (11) showed a significant increase in crop N removal while being N non-responsive with respect to DM yield. Therefore, crop N removal appears to be maximized when DM yield is maximized. For most sites, a corn silage crop can be expected to remove 220 kg N ha^{-1} or less. Additional N supplied beyond crop removal potential will not be taken up by plants, but will remain in the soil.

Nitrate-nitrogen distribution in soil profile

The concern regarding excessive N fertilization centers around potential groundwater contamination resulting from nitrate leaching during the rainy winter season. One factor which helps determine the magnitude of pollution risk is the

Table 19. T-test analysis of nitrogen removed in harvested corn data. Sites are listed in order of increasing PSNT values (mg NO_3-N kg^{-1} soil). Dotted line separates sites above and below PSNT critical value of 21 mg NO_3-N kg^{-1} soil. *, ** Significant difference between treatments at $P < 0.05$, 0.01, respectively.

Site No.	PSNT	mean N removed (kg N ha^{-1})		C.V.	T-test
	(mg NO_3-N kg^{-1})	0 kg N ha^{-1}	200 kg N ha^{-1}	(%)	P-value
12	7	92	130	11.1	0.01 *
15	16	100	127	11.9	0.07
21	16	173	241	10.3	0.01 *
3	18	122	147	3.5	0.00 **
8	23	157	164	14.2	0.46
1	25	203	197	7.2	0.56
6	28	113	126	8.7	0.12
22	28	195	210	8.7	0.83
14	33	202	242	6.1	0.01 *
5	35	174	189	10.6	0.32
7	35	177	189	7.1	0.27
2	37	213	212	18.5	0.97
16	38	187	192	8.5	0.98
13	39	192	191	12.6	0.97
23	40	234	283	8.9	0.05
17	41	141	145	8.1	0.87
11	46	190	215	3.2	0.00 **
10	47	215	237	7.3	0.11
24	52	242	244	4.8	0.47
20	55	238	279	7.0	0.15
9	55	187	179	10.5	0.58
18	56	202	229	8.6	0.06
19	57	212	219	7.1	0.93
25	62	209	220	4.1	0.95
4	64	184	185	13.5	0.97
26	81	220	218	10.0	0.70

amount of nitrate left in the soil profile after crop removal. Nitrate is expected to accumulate in the soil only after yields are maximized or limited by some factor other than N availability. Therefore, the amount of nitrate remaining in the soil is also a reflection of N management efficiency.

Fig. 9 shows the distribution of NO_3-N in the 150 cm soil profile at planting and after harvest for each site. Profile NO_3-N accumulation after harvest ranged from 18 to 1478 kg NO_3-N ha^{-1}, with 18 sites over 200 kg NO_3-N ha^{-1}. Changes in soil profile NO_3-N during the growing season ranged from -229 to +613 kg NO_3-N ha^{-1}. On 17 of the 26 sites, NO_3-N accumulated during the growing season, indicating that N had been supplied in excess of crop demand. Most of the increases occurred in the surface 30 cm. Growers on 14 of the 17 sites where NO_3-N accumulated had applied commercial N fertilizer to the corn fields. Reduction or elimination of commercial N fertilizer applications on those sites could reduce both farm operating costs and NO_3-N accumulations.

The NO_3-N distributions within soil profiles provide insight into the possible fate of excess NO_3-N. Sites 10 and 24, located on the same lagoon-irrigated field in 1993 and 1994, respectively, can be used as an example. At planting in 1993 (site 10), there were 253 kg NO_3-N ha^{-1} in the profile. Over half (139 kg NO_3-N ha^{-1}) of the nitrate was below 90 cm, and therefore was below the most effective rooting depth of corn. After harvest there were 616 kg NO_3-N ha^{-1} in the profile, indicating a 363 kg NO_3-N ha^{-1} increase during the growing season. The distribution curve shows most of the increase occurring in the surface 30 cm. Triticale was planted in the fall of 1993 and harvested in the spring of 1994.

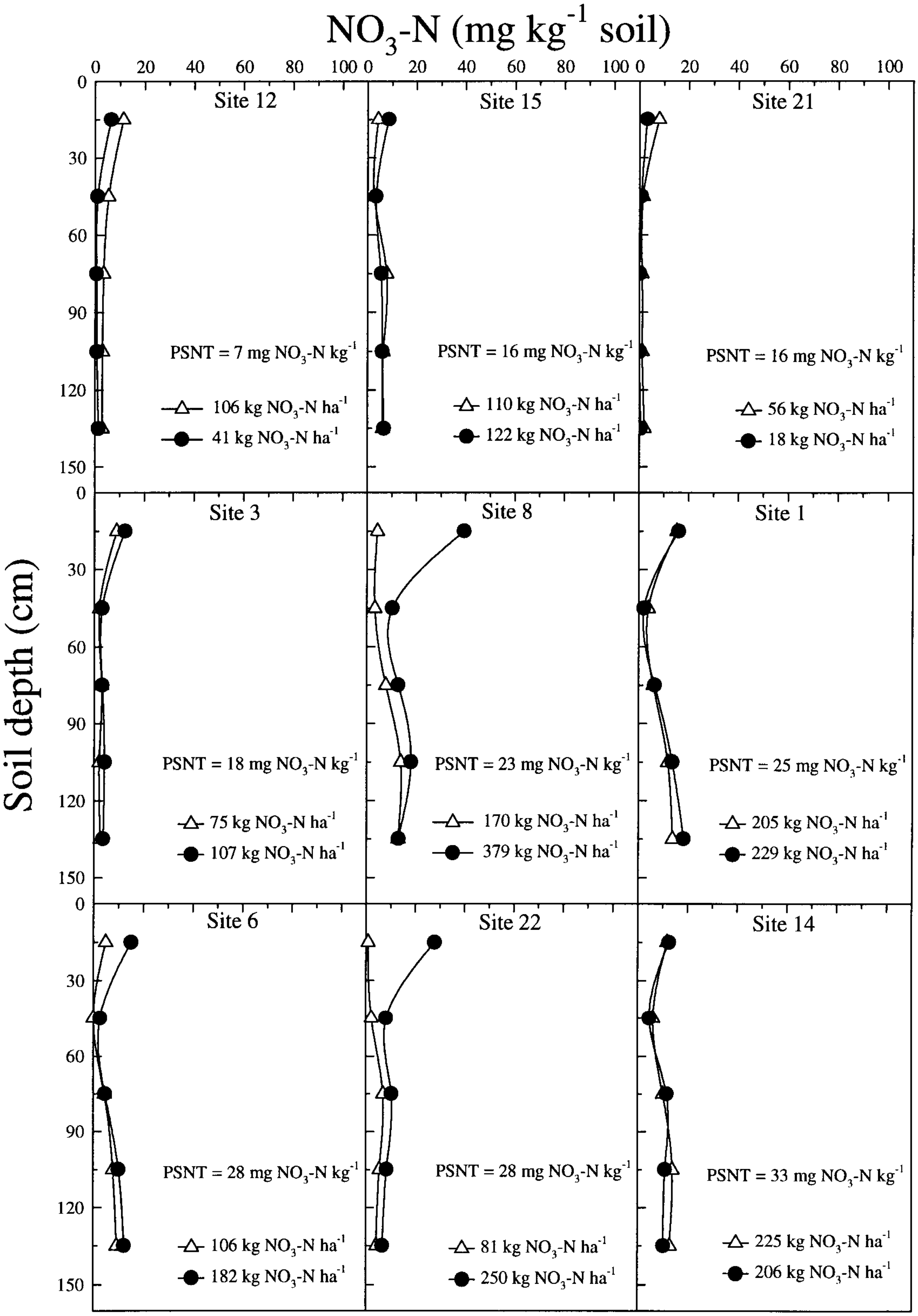

Fig. 9. Distribution of NO_3-N in 150 cm soil profile at planting (-△-) and at harvest (-●-). Sites are arranged in order of increasing PSNT values. Values in legend refer to NO_3-N accumulation in 150 cm profile.

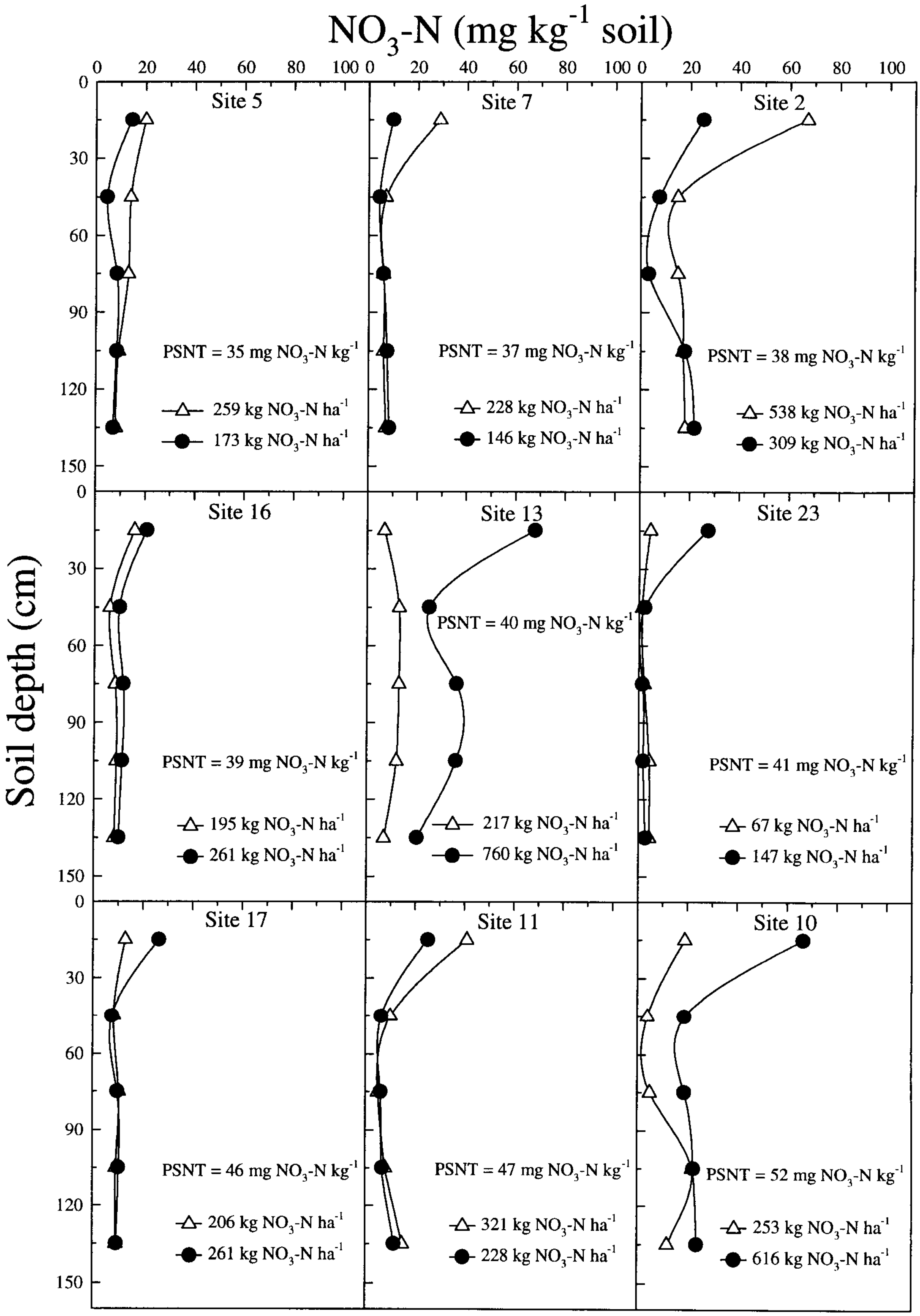

Fig. 9 (Continued).

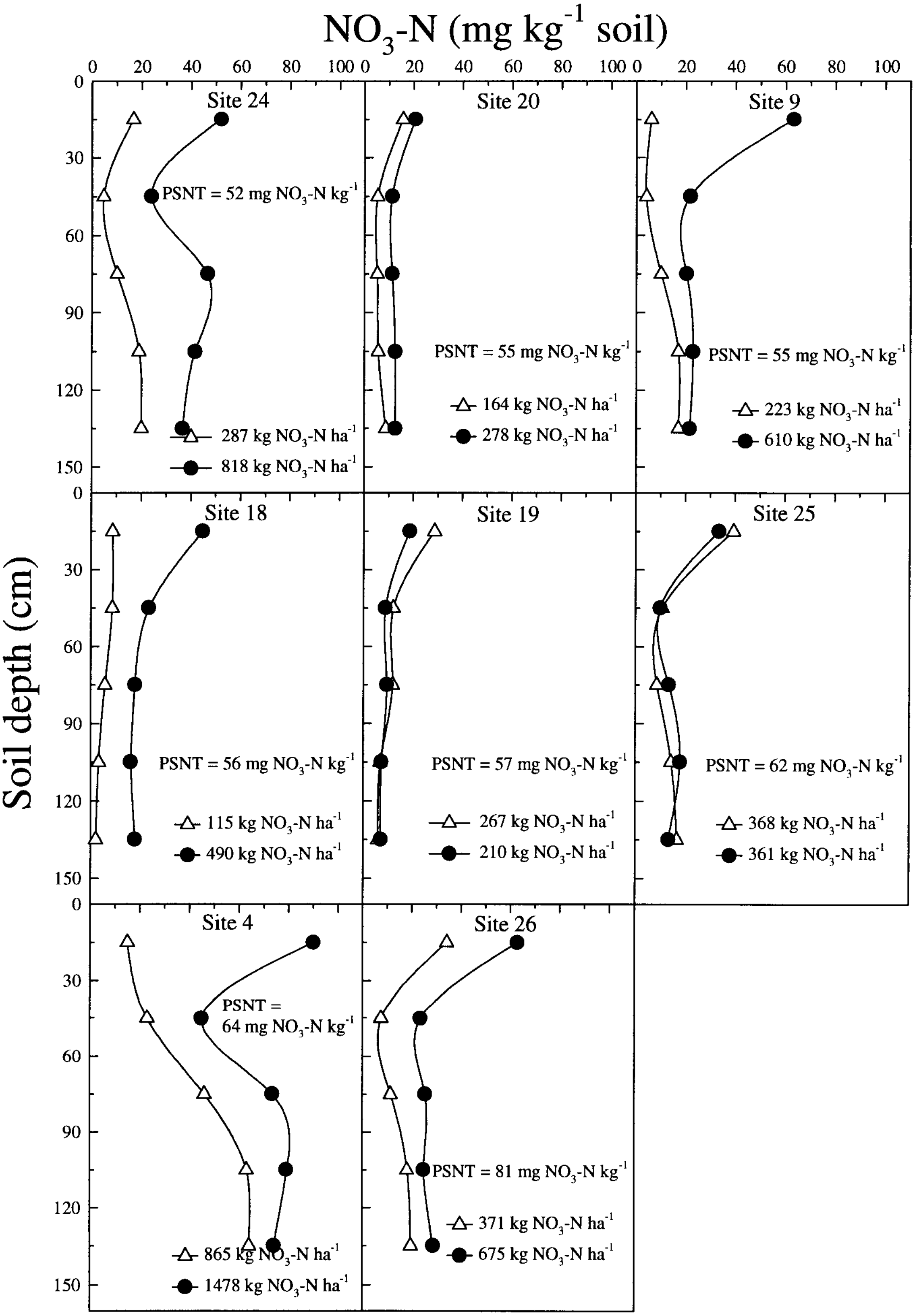

Fig. 9 (Continued).

During the period between 1993 corn harvest and 1994 corn planting (site 24), NO_3-N in the profile declined by 329 kg NO_3-N ha^{-1}. About 120 kg NO_3-N ha^{-1} of the over-winter decline in NO_3-N was accounted for in the harvested triticale. The unaccounted for 209 kg NO_3-N ha^{-1} may have been lost via leaching and denitrification. The accumulation of NO_3-N below 90 cm suggests that leaching has occurred.

For efficient nutrient cycling on dairies with high animal:acreage ratios, manure must be distributed on as much cropped land as possible. The affect of uneven distribution of manure on a farm is illustrated by sites 4 and 3. The sites were located on the same farm, but across the road from each other. Site 4 received manure lagoon applications and commercial N fertilizer. Site 3 received commercial N fertilizer only, as the grower was unable to pump manure lagoon water across the road. Soil at site 4 showed an increase of 613 kg NO_3-N ha^{-1} during the growing season, with 1478 kg NO_3-N ha^{-1} in the profile after harvest. Site 3, on the other hand, began and ended the season with 75 and 107 kg NO_3-N ha^{-1} in the profile, respectively. If the grower could devise a way to pump manure across the road and distribute manure on both fields, commercial N fertilizer purchases could probably be eliminated and NO_3-N accumulations on site 4 could be reduced.

Residual soil nitrate (RSN) in the surface 30 cm after harvest can often be used as an indication of RSN deeper in the soil profile. Coefficients of determination between RSN in the surface 30 cm and RSN to various profile depths are shown in Table 20.

Table 20. Coefficients of determination (r^2) and linear regression equations for residual soil nitrate (RSN) in the surface 30 cm vs. RSN to various profile depths.

	Profile depth			
	0 - 60 cm	0 - 90 cm	0 - 120 cm	0 - 150 cm
r^2	0.99	0.94	0.90	0.87
equation[†]	$y = -8.71 + 1.43x$	$y = -25.32 + 2.02x$	$y = -36.59 + 2.62x$	$y = -40.44 + 3.14x$

[†] y = RSN (kg NO_3-N ha^{-1}) to depth indicated by column heading; x = RSN (kg NO_3-N ha^{-1}) in surface 30 cm.

The correlation between RSN in the surface 30 cm and RSN in the 150 cm profile suggests that soil samples collected from the surface 30 cm may be used to identify sites with large pools of potentially leachable nitrate. The regression equations, however, should be used cautiously as a method for quantifying NO_3-N accumulations in soil profiles. The equations were derived from post-harvest soil data, and should not be used for other sampling times. Also, the data were collected primarily from sites with long histories of manure applications and corn production. The NO_3-N distributions in Fig. 9 show accumulations deep in soil profiles that may not be expected for other management scenarios. Therefore, the regression equations should not be applied to non-manured soils or other cropping rotations. Lastly, the data were collected on sites that were in equilibrium as a result of consistent management histories. Because NO_3-N deep in the profile reflects management history and not most recent management, extrapolations of surface data should be made cautiously on fields where management practices are in a state of transition.

Residual soil nitrate test

RSN measurements can be used not only to identify leaching risk, but also as a tool for evaluation of N management. The nitrate distribution curves for 150 cm soil profiles (Fig. 9) show that most of the changes observed between spring and fall sampling occurred in the surface 30 cm. Thus, RSN in the surface 30 cm reflects recent N management efficiency, and a sampling depth of 30 cm was determined optimum for the RSN test. The 30 cm sampling depth is also more practical than deep sampling and is more likely to be practiced.

RSN in the surface 30 cm ranged from 13 to 368 kg NO_3-N ha^{-1} (Table 21). Cate-Nelson analysis determined that a RSN critical value of 55 kg NO_3-N ha^{-1} separated N responsive from non-responsive sites (Table 22). A majority (77%) of the sites had RSN above the critical value. The CN plot shows one Type I error and two Type II errors, for an overall error rate of 12% (Fig. 10).

Type II errors were N responsive sites (10, 18) with higher than expected RSN. Sites 10 and 18 were Type II errors in PSNT and corn stalk NO_3-N analysis, as well. High RSN on N responsive sites may result from N supplied too late in the season for optimal crop use. If the N had been available earlier in plant development, it may have contributed to increased yield. Late season N supplies could result from N mineralization or late season fertilizer or lagoon manure applications.

Type I errors (site 7) were sites where yields were optimized and RSN was lower than predicted. Because low RSN is a goal of N management, optimum yield with unexpectedly low RSN is not a concern. Type I errors are of concern, however,

Table 21. Data for Cate-Nelson determination of critical value for residual soil nitrate (RSN) in surface 30 cm based on dry matter yield. Data are ranked in order of increasing RSN values.

Site No.	Residual soil nitrate (kg NO_3-N ha^{-1})	0 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	200 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	Relative Yield (%)
21	13	18.8	21.6	86.7
12	26	10.4	11.6	89.8
15	35	8.6	9.5	90.8
7	40	15.4	15.8	97.4
3	50	12.8	13.7	93.6
14	51	16.8	18.6	90.3
5	59	16.1	16.4	98.2
6	61	9.1	9.0	101.5
1	66	18.4	17.9	102.9
19	76	16.6	15.4	107.9
20	85	20.0	20.9	95.7
16	86	13.5	13.2	102.7
11	103	13.4	13.9	96.4
2	103	19.3	18.4	104.9
17	108	10.3	10.2	101.0
23	112	20.7	21.9	94.5
22	114	16.4	16.8	97.7
25	137	12.9	12.8	100.5
8	161	12.8	13.0	98.5
18	184	17.7	19.2	92.1
24	212	16.4	16.4	99.6
26	257	13.2	13.3	99.1
9	258	14.2	13.3	107.0
10	272	14.5	16.4	88.6
13	278	11.1	11.6	95.6
4	368	13.0	12.4	105.1

Table 22. Cate-Nelson analysis of residual soil nitrate (RSN) and dry matter yield data.

Highest RSN Value in Population 1	Mean Relative Yield Population 1	CSS-1[a]	Mean Relative Yield Population 2	CSS-2[b]	Postulated Critical Level	r^2 [†]
26	88.2	4.7	98.4	630.4	30	0.23
35	89.1	9.0	98.7	569.6	37	0.30
40	91.2	60.7	98.8	567.7	45	0.24
50	91.7	65.6	99.0	539.8	51	0.27
51	91.4	67.1	99.5	460.2	55 [‡]	0.36
59	92.4	106.2	99.5	458.4	60	0.32
61	93.5	178.6	99.4	454.4	64	0.23
66	94.6	256.4	99.2	441.8	71	0.15
76	95.9	416.7	98.7	361.6	80	0.06
85	95.9	416.8	98.9	352.2	85	0.07
86	96.5	459.4	98.6	336.5	94	0.04
103	96.5	459.4	98.8	331.3	103	0.04
103	97.1	525.6	98.3	290.8	106	0.01
108	97.3	540.3	98.0	282.5	110	0.00
112	97.2	547.7	98.4	269.0	113	0.01
114	97.2	548.0	98.5	268.4	125	0.01
137	97.4	558.3	98.2	263.7	149	0.00
161	97.4	559.5	98.2	263.6	172	0.00
184	97.2	586.3	99.2	221.1	198	0.02
212	97.3	592.0	99.1	220.9	234	0.02
257	97.4	595.2	99.1	220.9	257	0.01
258	97.8	684.6	96.4	136.3	265	0.01
272	97.4	765.1	100.3	45.1	275	0.02

N = 26; Total mean relative yield = 97.6; Total corrected sum of squares (TCSS) = 825.9.

[a] CSS-1 = corrected sum of squares of deviations from mean of population 1.

[b] CSS-2 = corrected sum of squares of deviations from mean of population 2.

[†] r^2 = [TCSS - (CSS-1 + CSS2)] / TCSS

[‡] Postulated critical level with highest r^2-value is best separation of two populations.

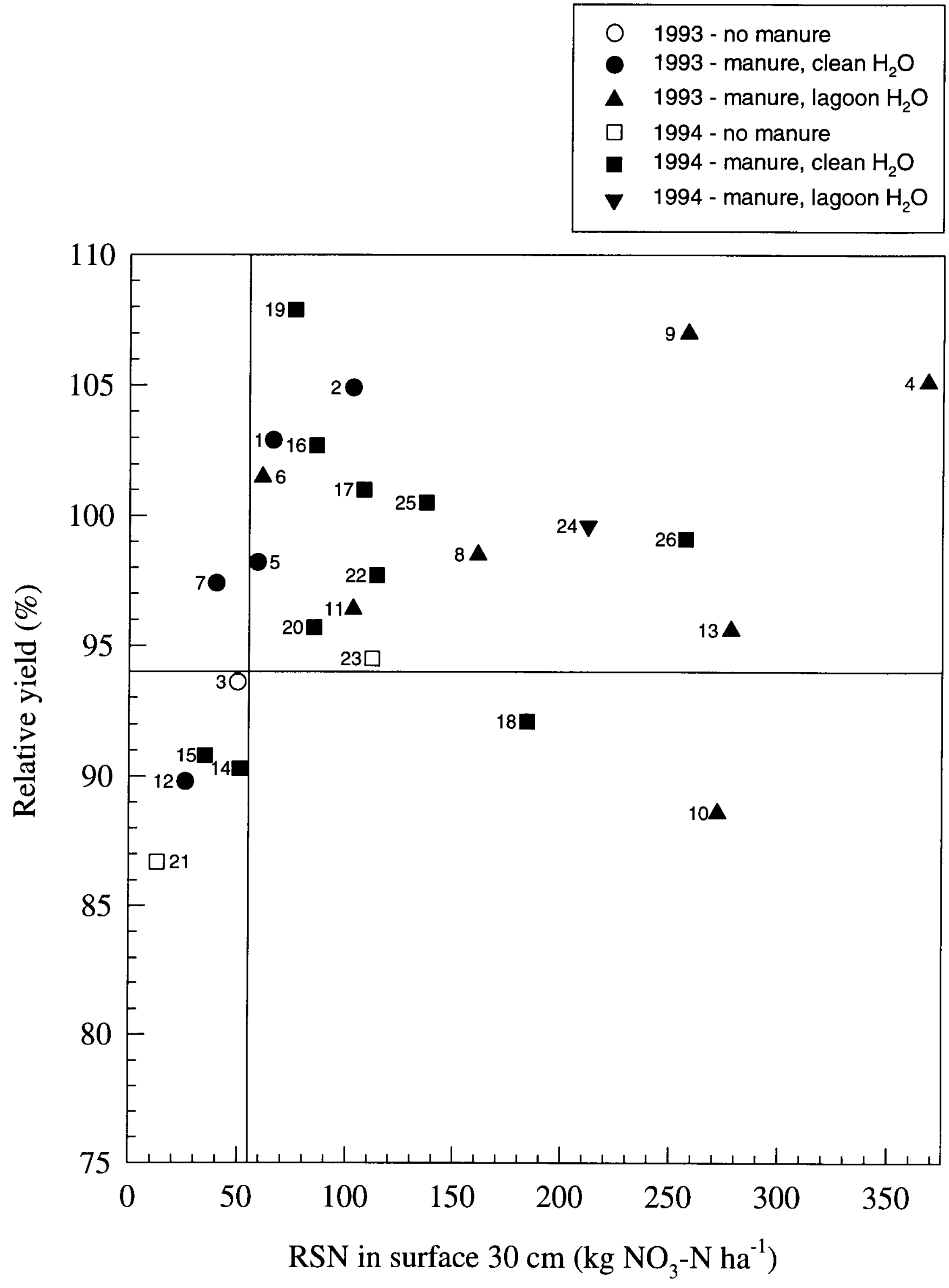

Fig. 10. Cate-Nelson plot of relative yield vs. residual soil nitrate (RSN) in surface 30 cm of soil. Numbers are site numbers.

if a grower interprets low RSN to be an indication of N deficiency when, in fact, yields were not N-limited.

A RSN target range of 50 to 65 kg NO_3-N ha^{-1} is suggested. This range corresponds to soil test values of about 12 to 16 mg NO_3-N kg^{-1} soil. The RSN test should be used cautiously as a diagnostic tool for identifying N deficient sites. The test is most useful for identifying sites where excessive N has been supplied.

Corn stalk nitrate at harvest

In annual crops, plant tissue tests have traditionally been used either to evaluate crop nutrient status in order to correct deficiencies during the growing season, or as a diagnostic tool to identify possible causes of poor crop performance. The corn stalk nitrate at harvest test evaluated in this study is a diagnostic tool used to evaluate N management, and provides useful information in cases of both good and poor crop performance.

Corn stalk nitrate concentration at harvest and relative yield data are shown in Table 23. A critical concentration of 3730 mg NO_3-N kg^{-1} was established using Cate-Nelson analysis (Table 24). The analysis correctly placed 88% of the data points (Fig. 11), which is the same prediction rate resulting from PSNT analysis. The three sites (10, 14, 18) located in the lower right quadrant are the same sites that were outliers in PSNT analysis.

Stalk NO_3-N concentrations at harvest were linearly correlated ($r^2 = 0.82$) with PSNT values (Fig. 12). Sites irrigated with lagoon water were not included in regression analysis. The correlation between PSNT values and stalk NO_3-N concentrations at harvest provides evidence that soil NO_3-N concentrations at the

Table 23. Data for Cate-Nelson determination of stalk nitrate at harvest critical value based on dry matter yield. Data are ranked in order of increasing stalk nitrate values.

Site No.	Stalk Nitrate (mg NO_3-N kg^{-1})	0 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	200 kg N ha^{-1} treatment Dry matter yield (Mg ha^{-1})	Relative Yield (%)
3	454	12.8	13.7	93.6
12	464	10.4	11.6	89.8
21	691	18.8	21.6	86.7
15	3007	8.6	9.5	90.8
22	4453	16.4	16.8	97.7
8	4690	12.8	13.0	98.5
14	5250	16.8	18.6	90.3
6	5388	9.1	9.0	101.5
17	7238	10.3	10.2	101.0
11	7268	13.4	13.9	96.4
1	7350	18.4	17.9	102.9
2	7385	19.3	18.4	104.9
23	7595	20.7	21.9	94.5
7	7598	15.4	15.8	97.4
9	7718	14.2	13.3	107.0
18	8344	17.7	19.2	92.1
4	8410	13.0	12.4	105.1
5	9185	16.1	16.4	98.2
20	9937	20.0	20.9	95.7
19	10173	16.6	15.4	107.9
13	10307	11.1	11.6	95.6
16	11624	13.5	13.2	102.7
10	12598	14.5	16.4	88.6
25	12910	12.9	12.8	100.5
24	14669	16.4	16.4	99.6
26	15931	13.2	13.3	99.1

Table 24. Cate-Nelson analysis of stalk nitrate at harvest data.

Highest Stalk NO_3-N Value in Population 1	Mean Relative Yield Population 1	CSS-1[a]	Mean Relative Yield Population 2	CSS-2[b]	Postulated Critical Level	r^2 [†]
464	91.7	7.5	98.1	742.5	578	0.09
691	90.0	24.1	98.6	606.6	1849	0.24
3007	90.2	24.5	99.0	542.4	3730 [‡]	0.31
4453	91.7	69.1	99.0	540.6	4572	0.26
4690	92.8	107.4	99.1	540.3	4970	0.22
5250	92.5	112.8	99.5	460.3	5319	0.31
5388	93.6	183.8	99.4	456.2	6313	0.23
7238	94.4	232.8	99.3	453.4	7253	0.17
7268	94.6	236.4	99.5	444.5	7309	0.18
7350	95.4	298.4	99.3	432.1	7368	0.12
7385	96.2	381.4	98.9	398.1	7490	0.06
7595	96.1	383.9	99.2	377.8	7597	0.08
7598	96.1	385.6	99.3	374.3	7658	0.08
7718	96.9	496.1	98.6	309.8	8031	0.02
8344	96.6	517.3	99.3	263.0	8377	0.06
8410	97.1	585.0	98.7	226.1	8798	0.02
9185	97.1	586.2	98.7	225.9	9561	0.02
9937	97.1	588.1	99.1	215.6	10055	0.03
10173	97.6	700.1	97.7	125.7	10240	0.00
10307	97.5	704.1	98.1	120.3	10966	0.00
11624	97.7	730.0	97.0	93.7	12111	0.00
12598	97.3	809.8	99.7	1.0	12754	0.02
12910	97.5	819.3	99.4	0.1	13790	0.01

N = 26; Total mean relative yield = 97.6; Total corrected sum of squares (TCSS) = 825.9.

[a] CSS-1 = corrected sum of squares of deviations from mean of population 1.

[b] CSS-2 = corrected sum of squares of deviations from mean of population 2.

[†] r^2 = [TCSS - (CSS-1 + CSS2)] / TCSS

[‡] Postulated critical level with highest r^2 value is best separation of two populations.

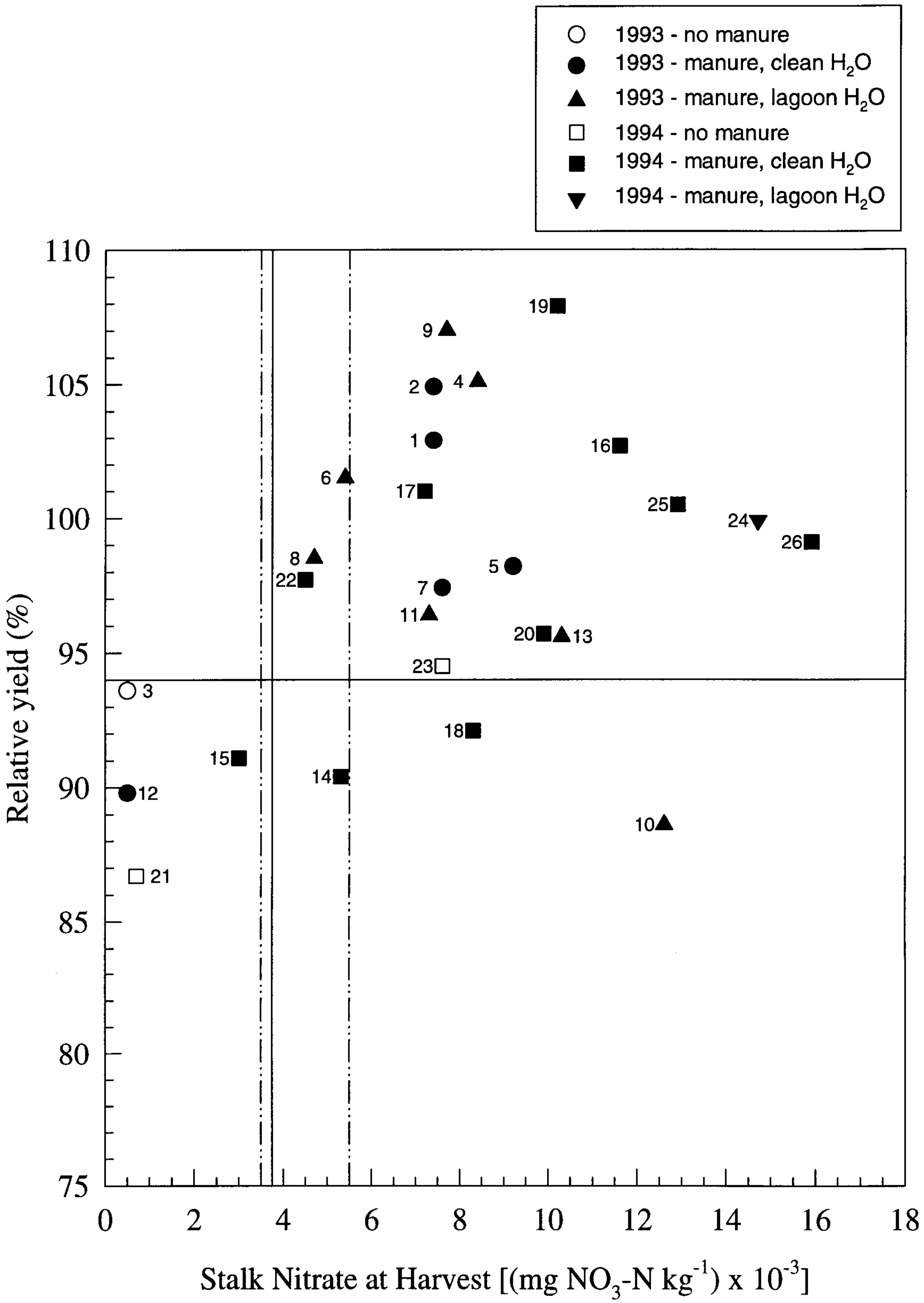

Fig. 11. Cate-Nelson plot of relative yield vs. stalk NO_3-N at harvest. Numbers are site numbers. Dotted lines show 3500 - 5500 mg NO_3-N kg^{-1} stalk nitrate critical range.

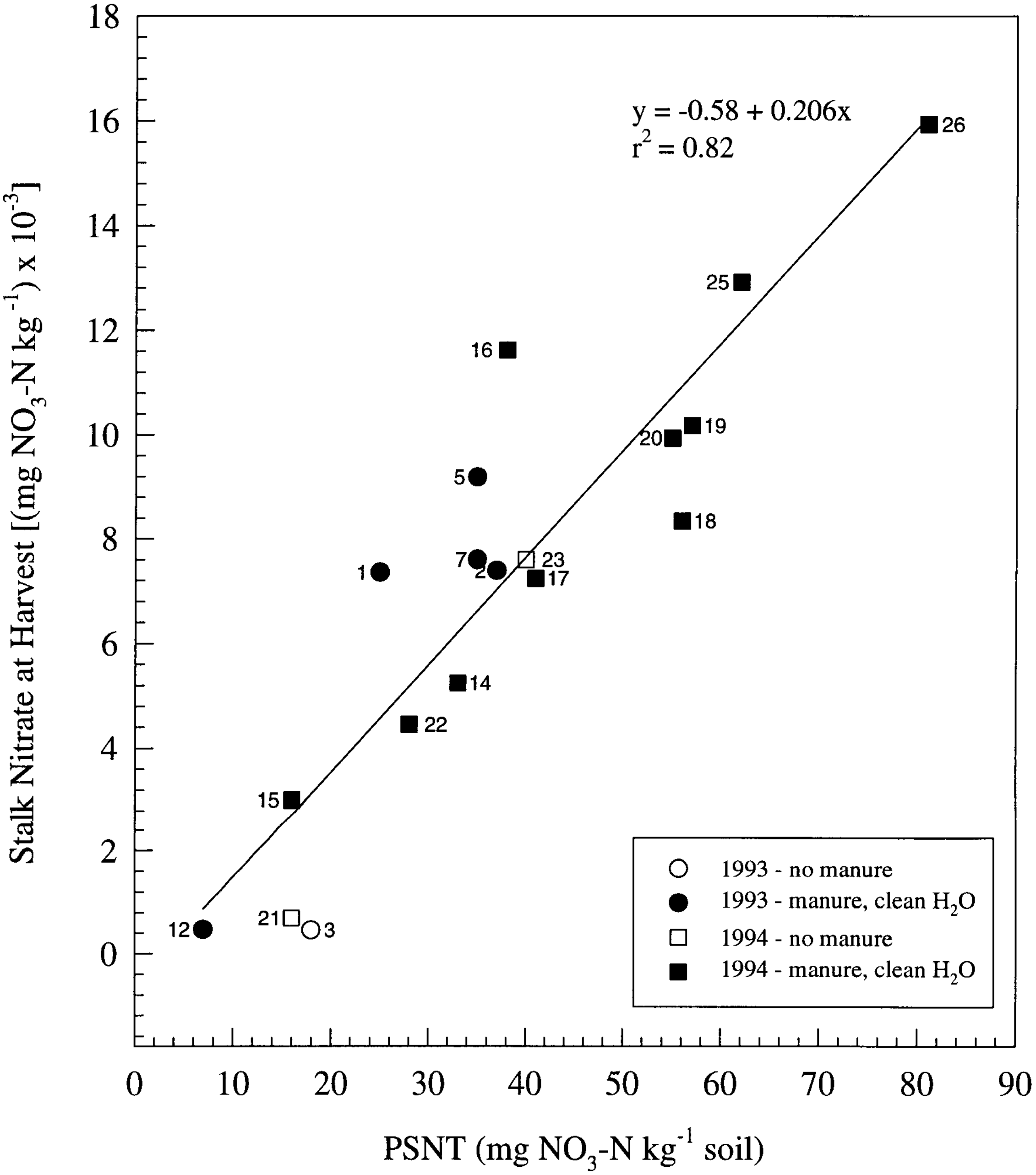

Fig. 12. Stalk nitrate at harvest vs. Pre-sidedress Soil Nitrate Test (PSNT). Numbers are site numbers.

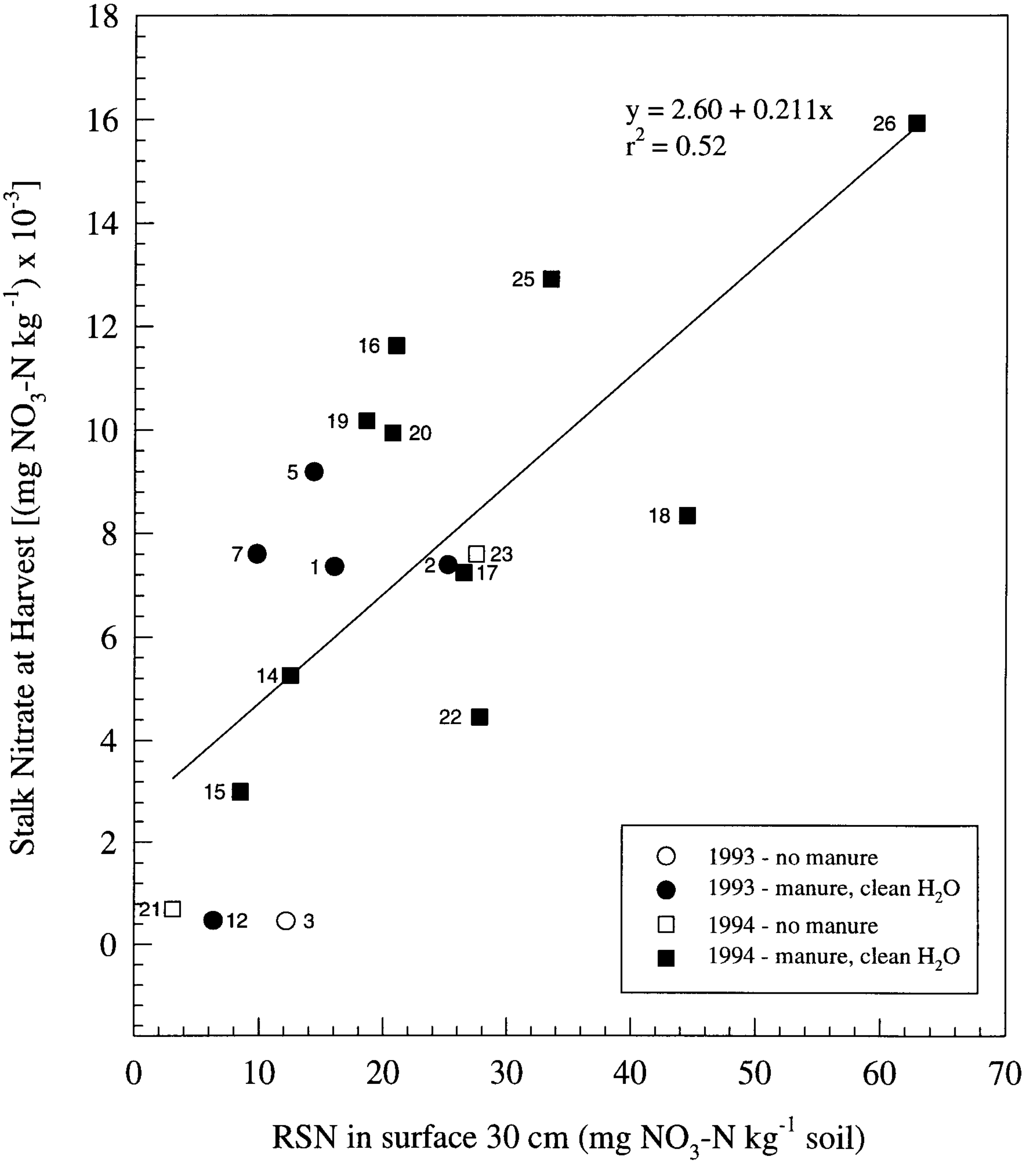

Fig. 13. Stalk nitrate at harvest vs. residual soil nitrate (RSN) in surface 30 cm of soil. Numbers are site numbers.

V5/V6 growth stage are a good predictor of subsequent crop N status. The correlation existed across sites with diverse corn cultivars, irrigation practices, and manure management histories. Stalk NO_3-N concentrations were more weakly correlated ($r^2 = 0.52$) with harvest soil NO_3-N concentrations (Fig. 13) than with PSNT values. The stronger correlation between stalk NO_3-N concentrations and PSNT NO_3-N concentrations suggests that soil N supply just prior to the period of greatest crop demand has greater influence on crop N status than does late season soil N supply. Also, the relatively weak correlation between stalk NO_3-N and RSN suggests that caution should be exercised when using RSN values to evaluate crop N status.

Critical nutrient concentration ranges provide more useful information than discreet statistical separations. Deficient and excessive ranges do not border on each other, but are separated by a sufficient range. The regression equation relating PSNT and stalk NO_3-N values was used to identify a stalk NO_3-N sufficient range of 3500-5500 mg NO_3-N kg^{-1}, which correlates with a PSNT range of 20 - 30 mg NO_3-N kg^{-1}. This stalk NO_3-N sufficiency range is considerably higher than the 700-2000 mg NO_3-N kg^{-1} range reported by Binford et al. (1992b) for field corn grown for grain. Corn grown for silage is harvested at the R4 stage of development, while corn grown for grain is harvested at the physiologically mature R6 stage. Because stalk nitrate concentrations decline as corn plants mature, concentrations are expected to be higher when the crop is harvested for silage as compared to grain. Therefore, the critical range identified in this research does not conflict with the research of Binford et al. (1992b).

Because the stalk nitrate test is performed at harvest, it does not aid in N management in the current year. The test can, however, be a valuable diagnostic tool and influence management decisions in subsequent growing seasons. Growers adopting new management practices involving lower N inputs are most likely to benefit. When transitional growers encounter yields that are lower than desired, lowered N rates may be the suspected cause. The harvest stalk nitrate test can help determine whether N was, in fact, the yield limiting factor. If the stalk nitrate test indicates N was not limiting, a grower may avoid returning to higher N rates unnecessarily. Similarly, a grower who has had success at lowering N rates may use the stalk nitrate test to decide whether further N reductions are advisable in future years.

SUMMARY AND CONCLUSION

The soil and plant tissue analyses evaluated in this thesis can be combined as components of a nitrogen monitoring program for silage corn production. While there is no need to make use of all methods in a single year, having an array of options should increase the likelihood that a given producer can develop a program that fits into his/her overall farm management program.

The SNAP test is useful only for identifying sites that are not likely to respond to N fertilization. If SNAP values are above 25 mg NO_3-N kg^{-1}, soil N supply is probably sufficient for maximum yields. If SNAP values are below 25 mg NO_3-N kg^{-1}, the PSNT should be performed when corn is at the V5/V6 growth stage. The SNAP test was not able to predict N mineralization, and a large percentage of sites with SNAP values below 25 mg NO_3-N kg^{-1} had PSNT values above 25 mg NO_3-N kg^{-1}. Though the SNAP provides less information than the PSNT, the advantage of early soil testing may be attractive to some growers.

The PSNT is a "yes or no" test to determine if additional N fertilization is likely to increase yields. A PSNT critical value of 25 mg NO_3-N kg^{-1} is suggested. This is slightly higher than the 21 mg NO_3-N kg^{-1} critical value determined by analyzing research data. The 25 mg NO_3-N kg^{-1} value allows a margin of error and is consistent with critical values in other states. From a practical standpoint, the difference between the two values is minimal.

If PSNT values are above 25 mg NO_3-N kg^{-1}, no additional N fertilization is recommended. When the PSNT is below 25 mg NO_3-N kg^{-1}, N fertilization is likely to increase yields. Questions will arise regarding how much N to apply. While there is no response function to base recommendations upon, it is reasonable to expect that as PSNT values increase, fertilizer N requirements decrease. Based on this principle and a target rate of 180 lb N/acre for maximum yield, N recommendations were established and are shown in Table 25. The recommendations are consistent with rates derived using Magdoff et al.'s (1990) equation (Eq.2) for PSNT based fertilizer recommendations.

Table 25. Suggested N fertilization rates based on PSNT values.

PSNT value (mg NO_3-N kg^{-1})	Estimated N to apply (lb N/acre)
0 - 10	100 - 175
10 - 20	50 - 100
20 - 25	0 - 50
over 25	0

Corn stalk nitrate concentrations at harvest can be used to evaluate N management. The stalk nitrate test is a direct measurement of plant nutrient status, and is therefore the best method for determining if crop yields were N-limited. A guide for interpretation of stalk nitrate values is shown in Table 26.

Table 26. Interpretation of corn stalk nitrate concentrations at harvest.

Stalk NO_3-N concentration at harvest	Diagnosis
< 3500 ppm	N deficient, N may have limited yield
3500 - 5500 ppm	N sufficient for optimum yield
> 5500 ppm	N supplied in excess of crop demand

Residual soil nitrate can be used to identify sites where N has been supplied in excess of crop demand. Residual soil nitrate should be less than 65 kg NO_3-N ha^{-1} (16 mg NO_3-N kg^{-1} soil) in the surface 30 cm. Low levels of residual soil nitrate do not necessarily indicate N deficiency. Nitrogen deficiency is best diagnosed using the stalk nitrate test. Residual nitrate in the surface 30 cm is an indication of nitrate accumulation in the 150 cm profile on sites with consistent management histories. As management practices change and equilibrium is disrupted, residual nitrate in the surface 30 cm should be interpreted only to reflect most recent practices.

The UV205 method needs further study before it can be used with confidence. Modifications of the method may reduce interferences resulting from bicarbonate and filtration. With a 16.7% error rate, the method appears promising. The failure to identify two sites with low soil nitrate and large mineralizable N pools as N non-responsive, however, raises questions regarding the method's ability to predict soil nitrogen supplying capability. The potential for early identification of N responsive sites warrants further investigation of the UV205 method.

Nitrogen sufficient for maximum dry matter yields is also sufficient for maximum silage protein concentrations. Excess N is not absorbed by the crop and is left in the soil, increasing the risk of nitrate contamination of groundwater. On most sites, a silage corn crop can remove a maximum of approximately 220 kg N ha^{-1}.

The small number of N responsive sites encountered in this research suggests considerable opportunity for reduction of fertilizer N inputs on many Willamette Valley dairies. Reduction of fertilizer use can result in significant economic savings for producers. Concurrently, the risk of nitrate contamination of surface and ground waters will be reduced. Monitoring of nitrogen will lead to increased awareness of on-farm nitrogen dynamics, and will facilitate changes in management practices.

AFTERWARD

The management tools explored in this research are of potential use to growers who wish to increase N management efficiency and reduce fertilizer inputs. The amount and profile distribution of residual nitrate measured on some dairy fields, however, raises questions regarding the degree to which fertilizer reductions will alleviate nutrient loading problems. Whether management practices change and the degree to which environmental damage from dairy practices can be minimized is dependent on factors other than the development of new technology. The determining factors are largely economic, social, and perceptual, not scientific.

One of the first changes needed is in the perception of manure. On many dairies, manure is thought of as a disposal problem and handled accordingly. Manure is not generally thought of nor managed as a fertilizer. As a result, commercial fertilizers are often applied in addition to manure on fields where manure nutrients are more than adequate for crop production. This practice is inefficient economically, as the purchased fertilizer and the labor and machinery involved in application often represent unnecessary expenditures. If manure is perceived and managed as a fertilizer material, dairy profits and environmental protection will both increase.

A related issue concerns cropping systems and timing of manure application. Manure storage facilities are typically emptied in the fall in preparation for winter when application is discouraged. Fall applications are often made on recently harvested corn fields. Because there is no growing crop on those fields, nutrients remain in the soil. The argument often made in defense of this practice is that inorganic N in manure is predominantly in the form of ammonium (NH_4^+) which will adsorb to cation exchange sites on soil colloids. The perception is that nitrification of NH_4^+ will not occur before winter precipitation begins because soils are too cold for biological activity. Soil temperatures in the Willamette Valley in the fall are, however, high enough for nitrification, and fall manure applications on bare ground are likely to increase the leachable nitrate pool. Reduction of fall manure applications is difficult without investing in larger manure storage facilities. The environmental risk could be lessened, however, by applying manure to a growing crop as opposed to bare ground. This could be accomplished by adding crops such as perennial grasses to the cropping system, and possibly reducing corn acreage.

To address dairy nutrient problems we must move beyond crop production nitrogen balances and examine the whole farm system. Nitrogen comes onto the farm in feeds and fertilizers and leaves the farm in milk, animal removal, and losses to the environment. Because cows are not entirely efficient in feed digestion, approximately 75% of feed N ends up in manure. Manure N is either cycled back into feed via crop production, exported from the farm, or lost to the environment. The amount of N that can be cycled into feed is limited by crop production potential. In general, exportation of manure is not economically feasible and is rarely practiced. The only remaining pathway for manure N is loss to the environment. Losses in the form of ammonia volatilization are often encouraged to decrease soil nutrient loading. While volatilization is viewed as acceptable today, it does not represent a long term solution to the problem. Atmospheric ammonia contributes to acid rain, and undoubtedly this will become an issue in manure management in the near future. Excess manure N that is not volatilized is lost via denitrification, surface runoff, or leaching.

The current trend of increasing herd sizes and animal:acreage ratios threatens the environmental sustainability of western Oregon dairies. Increased animal numbers translate into increased N coming onto the farm in feeds and increased manure production. Acreages rarely increase in proportion to herd increases. Many dairies are already faced with manure nutrient excesses, and larger herd sizes aggravate the problems. Even with the best possible management of manure and cropping systems, there is a limit to the amount of manure a given piece of land can cycle without creating a pollution hazard.

Modern agriculture is business, and in business growth can spread like a disease. Dairies are not immune. Increased herd size and manure production inevitably leads to construction of larger manure storage facilities. Manure storage facilities are costly and often increase farm debt. Increased debt load generates the need for increased cash flow, which requires increased milk production. And so the spiraling cycle of expansion proceeds. Government programs that encourage such growth and subsidize surplus production need to be reformed to encourage sustainability of smaller, more economically and environmentally sound production systems.

All is not bleak. Willamette Valley agriculture has escaped the regionalization and loss of diversification most of the country has experienced as described by Lanyon (1995). Dairies are scattered along the length of the valley, intermingled with diverse annual and perennial crops. Many opportunities exist for dairy manure to be spread on neighboring crop lands. Neighboring farms can benefit from manure nutrients and improved soil quality resulting from organic matter inputs. Dairies can benefit by reducing soil nutrient loading. The major obstacle preventing off-dairy manure distribution is the high cost of moving and spreading manure. Perhaps the greatest contribution technology can make to alleviating dairy manure problems is the development of economical methods of processing and distributing manure to off-dairy sites. I guess that is why God created engineers. To move manure.

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APPENDICES

Appendix 1. Soil NO_3-N and NH_4-N in the 150 cm soil profile at planting and after harvest. After harvest data are shown for each treatment.

		At planting		After harvest 0 kg N ha^{-1}		After harvest 200 kg N ha^{-1}	
Site No.	Depth (cm)	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})
1	0-30	15.3	3.2	16.0	3.4	42.7	6.8
1	30-60	3.9	2.4	2.1	2.1	5.1	1.4
1	60-90	5.9	2.2	6.4	4.0	6.4	2.5
1	90-120	11.8	3.6	13.6	2.1	13.9	2.2
1	120-150	13.8	1.9	18.3	2.8	16.6	2.4
2	0-30	66.9	4.8	25.2	7.3	48.5	11.2
2	30-60	15.3	2.5	7.6	2.1	11.3	3.0
2	60-90	14.9	3.8	3.2	2.6	11.4	2.3
2	90-120	16.8	1.8	17.8	1.5	27.2	2.5
2	120-150	17.8	2.1	21.7	1.0	28.0	1.5
3	0-30	8.9	10.3	12.2	6.0	Missing	
3	30-60	2.0	3.0	3.2	3.9		
3	60-90	3.0	2.5	3.2	2.7		
3	90-120	2.0	2.6	4.1	7.1		
3	120-150	2.5	2.3	3.6	3.6		
4	0-30	15.3	2.8	90.1	6.7	81.4	11.5
4	30-60	23.3	1.4	44.9	2.7	64.0	1.7
4	60-90	45.6	1.4	73.5	2.2	93.6	2.5
4	90-120	63.4	1.5	79.2	2.8	95.3	3.0
4	120-150	63.9	1.7	74.0	3.1	90.7	3.8
5	0-30	19.5	1.7	14.4	4.0	53.8	16.3
5	30-60	13.7	2.1	4.5	2.7	13.5	3.6
5	60-90	12.8	3.6	8.4	3.1	13.2	5.0
5	90-120	8.9	2.5	8.3	4.7	16.1	7.3
5	120-150	8.4	2.4	7.0	2.6	17.6	5.9
6	0-30	4.9	4.3	15.0	4.1	32.2	8.5
6	30-60	0.0	2.9	2.6	2.6	6.4	2.3
6	60-90	4.4	2.8	4.6	3.5	7.4	3.0
6	90-120	7.8	2.9	10.1	4.1	10.5	2.4
6	120-150	9.3	2.5	12.3	5.6	9.3	2.5
7	0-30	28.7	3.8	9.8	3.8	5.9	4.9
7	30-60	6.9	1.8	4.4	3.3	13.8	2.3
7	60-90	6.4	1.9	5.9	2.3	11.5	3.2
7	90-120	6.4	2.3	7.4	2.8	11.6	2.7
7	120-150	7.4	2.4	8.3	4.3	11.2	3.3
8	0-30	4.2	1.4	39.4	6.3	56.4	8.8
8	30-60	3.2	2.0	10.3	1.6	9.6	1.7
8	60-90	7.7	2.0	12.8	2.1	15.3	2.5
8	90-120	13.9	2.4	18.0	2.5	21.0	2.6
8	120-150	12.9	1.7	12.9	2.0	17.4	3.7
9	0-30	5.9	1.9	63.1	5.8	79.2	6.6
9	30-60	4.5	1.6	21.6	1.7	25.0	1.6
9	60-90	9.9	1.7	20.2	3.4	24.7	3.4
9	90-120	17.3	2.6	22.7	2.8	24.2	3.0
9	120-150	16.8	1.6	21.5	2.9	20.7	3.0

Appendix 1 (continued)

		At planting		After harvest 0 kg N ha^{-1}		After harvest 200 kg N ha^{-1}	
Site No.	Depth (cm)	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})
10	0-30	18.8	2.7	66.5	12.3	Missing	
10	30-60	4.0	2.2	18.9	3.3		
10	60-90	5.0	2.6	18.9	3.9		
10	90-120	21.8	1.6	22.5	3.0		
10	120-150	12.3	1.9	23.9	2.5		
11	0-30	40.7	2.7	25.1	3.8	60.9	7.3
11	30-60	10.4	1.5	6.3	2.4	13.3	2.4
11	60-90	4.9	2.2	6.1	2.8	11.0	2.8
11	90-120	7.8	3.1	6.7	3.4	8.5	3.1
11	120-150	14.8	2.8	11.7	2.8	11.0	6.6
12	0-30	11.3	4.0	6.4	12.1	30.7	11.0
12	30-60	5.4	4.0	1.0	3.8	7.1	6.1
12	60-90	3.4	3.3	0.6	4.4	4.6	3.1
12	90-120	2.9	3.1	0.8	3.1	3.8	2.8
12	120-150	2.9	2.3	1.4	3.1	4.8	3.3
13	0-30	7.4	3.6	67.9	6.2	84.2	13.6
13	30-60	12.8	4.5	25.3	2.9	29.6	3.8
13	60-90	13.2	3.7	36.4	2.6	36.1	3.6
13	90-120	12.3	2.7	36.1	2.8	31.4	3.6
13	120-150	7.4	2.2	20.4	2.0	32.2	3.4
14	0-30	11.8	3.0	12.5	4.4	14.1	4.0
14	30-60	6.2	2.0	4.7	3.2	8.1	2.3
14	60-90	10.1	2.4	11.7	3.0	14.7	2.5
14	90-120	14.0	2.3	11.0	2.1	14.2	2.1
14	120-150	12.9	3.4	10.4	2.4	13.1	2.9
15	0-30	4.3	5.0	8.5	3.6	12.3	4.3
15	30-60	2.6	2.5	3.4	1.8	4.0	1.5
15	60-90	7.8	3.4	5.4	2.1	6.1	2.5
15	90-120	6.4	3.5	6.0	2.6	7.2	2.8
15	120-150	6.1	4.4	6.6	2.7	6.7	2.6
16	0-30	16.1	4.8	21.0	18.8	34.6	25.4
16	30-60	6.2	4.5	10.0	8.2	15.1	9.1
16	60-90	8.3	4.1	11.7	6.4	16.5	7.8
16	90-120	8.9	3.3	11.2	4.8	15.2	5.3
16	120-150	8.2	3.3	9.9	3.4	11.8	3.8
17	0-30	13.0	3.0	26.5	5.5	38.4	6.7
17	30-60	8.3	3.1	7.6	3.6	9.5	5.2
17	60-90	10.5	5.7	9.8	3.7	9.4	3.2
17	90-120	9.3	3.5	10.4	3.6	10.3	3.6
17	120-150	9.3	3.2	9.5	3.1	9.5	4.1
18	0-30	8.6	5.2	44.9	6.5	Missing	
18	30-60	8.6	3.7	23.3	4.9		
18	60-90	5.7	6.1	17.7	4.0		
18	90-120	3.1	8.5	16.1	4.2		
18	120-150	2.1	8.1	17.8	5.4		

Appendix 1 (continued)

		At planting		After harvest 0 kg N ha^{-1}		After harvest 200 kg N ha^{-1}	
Site No.	Depth (cm)	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})
19	0-30	28.7	3.8	18.6	5.6		
19	30-60	12.0	3.8	8.9	4.5	Missing	
19	60-90	11.8	3.5	9.5	3.4		
19	90-120	6.8	2.8	7.3	3.0		
19	120-150	6.0	3.0	7.0	3.5		
20	0-30	15.6	13.9	20.7	4.6		
20	30-60	5.3	2.7	11.1	2.1	Missing	
20	60-90	5.1	2.2	11.2	4.2		
20	90-120	5.6	2.0	12.4	4.3		
20	120-150	8.7	2.5	12.5	2.6		
21	0-30	8.0	5.0	3.1	2.5	18.8	15.6
21	30-60	1.5	2.6	0.8	2.7	10.5	9.4
21	60-90	1.1	2.2	0.0	2.2	6.9	6.6
21	90-120	1.2	2.5	0.0	2.1	5.3	5.0
21	120-150	2.0	2.3	0.5	1.6	4.9	4.3
22	0-30	0.9	5.3	27.8	4.8	39.7	4.3
22	30-60	2.2	3.7	8.1	2.5	13.4	3.6
22	60-90	7.0	3.5	10.3	4.0	12.0	4.1
22	90-120	5.5	3.3	8.3	2.8	8.1	3.2
22	120-150	4.2	5.1	6.6	2.8	6.8	3.4
23	0-30	4.5	4.4	27.5	5.2	47.5	10.5
23	30-60	1.3	3.1	2.4	2.8	6.6	2.8
23	60-90	2.1	3.1	1.5	3.0	3.6	3.3
23	90-120	4.3	2.7	1.8	2.6	4.5	2.9
23	120-150	4.3	2.6	2.8	4.7	5.9	5.1
24	0-30	16.7	3.9	51.9	3.5		
24	30-60	4.6	3.1	23.9	2.3	Missing	
24	60-90	10.1	3.0	46.5	2.3		
24	90-120	19.0	2.4	41.4	3.1		
24	120-150	19.9	2.6	36.5	2.2		
25	0-30	39.4	4.2	33.5	3.6	44.1	3.8
25	30-60	10.7	3.4	9.9	3.5	10.1	4.3
25	60-90	8.7	4.1	13.5	3.9	13.8	3.9
25	90-120	14.4	3.9	18.0	3.2	15.3	3.4
25	120-150	16.8	4.8	13.3	2.7	16.4	3.2
26	0-30	34.2	4.0	62.8	4.8	68.7	5.6
26	30-60	7.5	2.5	23.4	3.4	20.7	3.2
26	60-90	11.4	2.3	25.4	3.3	27.7	2.4
26	90-120	18.1	3.5	24.8	2.9	26.7	2.8
26	120-150	19.7	3.4	28.7	2.4	29.1	2.8

Appendix 2. Soil NO_3-N and NH_4-N in the surface 30 cm when corn was at the V5 to V6 growth stage.

Site No.	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})
1	25.2	3.0
2	36.7	8.2
3	18.1	4.5
4	63.6	8.4
5	35.4	4.9
6	28.2	3.8
7	35.1	4.1
8	23.0	10.7
9	55.0	6.5
10	47.5	23.1
11	46.0	5.9
12	7.0	11.0
13	39.0	7.3
14	33.3	2.5
15	16.2	3.1
16	38.2	12.4
17	40.8	7.7
18	55.8	15.6
19	57.3	3.6
20	54.5	8.2
21	16.3	2.6
22	28.2	3.4
23	39.6	6.1
24	52.3	10.2
25	62.2	3.2
26	81.2	3.2

Appendix 3. Soil NO_3-N and NH_4-N in the surface 30 cm shortly after planting, 1994 sites only

Site No.	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})
14	28.7	3.6
15	13.1	3.2
16	24.2	3.1
17	25.4	2.6
18	40.5	4.9
19	36.2	2.7
20	63.4	7.5
21	32.1	8.5
22	10.7	4.3
23	30.0	18.0
24	36.9	4.9
25	40.2	4.9
26	80.3	22.7

Appendix 4. Soil pH and extractable phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) in the surface 30 cm.

Site No.	pH	P (ppm)	K (ppm)	Ca (meq/100g)	Mg (meq/100g)
1	6.0	173	511	10.6	2.9
2	6.1	200	1716	12.7	5.9
3	5.4	37	242	7.5	1.3
4	6.4	138	1338	8.8	3.8
5	6.2	85	394	9.0	2.5
6	5.9	126	464	7.1	2.3
7	6.2	109	433	9.1	1.6
8	6.0	71	417	11.2	2.9
9	6.0	106	651	9.9	3.0
10	6.2	210	764	8.4	2.8
11	6.1	113	371	7.7	2.2
12	6.4	28	332	31.4	8.6
13	5.8	62	1073	11.7	4.8
14	6.0	134	487	6.5	1.2
15	6.3	90	604	7.7	1.4
16	5.8	53	276	6.7	1.8
17	5.4	61	120	6.2	1.0
18	5.4	9	327	7.8	2.1
19	5.9	43	195	6.9	1.5
20	6.2	123	698	6.0	1.9
21	6.4	99	230	14.4	3.1
22	5.8	32	113	8.3	2.6
23	5.3	118	273	7.3	1.4
24	6.3	138	686	7.7	2.7
25	6.3	106	351	9.9	2.5
26	6.3	166	432	8.6	2.6

Appendix 5. Extractable soil phosphorus (P) and potassium (K) in the 150 cm soil profile at planting and after harvest, 1993 sites only.

	Sample depth	At planting		After harvest	
Site No.	(cm)	P (ppm)	K (ppm)	P (ppm)	K (ppm)
1	0 - 30	109	319	139	456
1	30 - 60	25	144	33	222
1	60 - 90	12	128	12	144
1	90 - 120	8	124	6	109
1	120 - 150	8	132	8	129
2	0 - 30	213	1103	192	1209
2	30 - 60	68	920	91	1170
2	60 - 90	37	725	42	1209
2	90 - 120	24	600	19	1107
2	120 - 150	19	390	16	756
3	0 - 30	33	195	42	226
3	30 - 60	20	128	16	120
3	60 - 90	16	144	15	117
3	90 - 120	12	167	12	120
3	120 - 150	13	152	10	128
4	0 - 30	130	1103	112	1092
4	30 - 60	34	581	25	440
4	60 - 90	18	300	18	198
4	90 - 120	15	230	15	175
4	120 - 150	14	206	14	156
5	0 - 30	52	257	74	323
5	30 - 60	26	179	27	202
5	60 - 90	29	159	21	179
5	90 - 120	16	156	17	144
5	120 - 150	16	148	15	136
6	0 - 30	97	409	119	429
6	30 - 60	36	249	35	276
6	60 - 90	30	210	29	148
6	90 - 120	27	167	26	132
6	120 - 150	23	163	20	132
7	0 - 30	73	284	96	289
7	30 - 60	27	113	40	156
7	60 - 90	11	124	13	129
7	90 - 120	10	132	11	129
7	120 - 150	10	136	13	137
8	0 - 30	81	335	82	437
8	30 - 60	22	132	16	152
8	60 - 90	18	124	12	109
8	90 - 120	11	113	7	94
8	120 - 150	12	105	7	86
9	0 - 30	79	343	127	624
9	30 - 60	30	152	43	234
9	60 - 90	23	124	30	152
9	90 - 120	17	105	30	152
9	120 - 150	15	117	26	133

Appendix 5 (continued)

Site No.	Sample depth (cm)	At planting P (ppm)	At planting K (ppm)	After harvest P (ppm)	After harvest K (ppm)
10	0 - 30	136	479	126	741
10	30 - 60	66	230	59	343
10	60 - 90	44	226	46	288
10	90 - 120	36	249	42	241
10	120 - 150	37	237	35	206
11	0 - 30	86	429	123	351
11	30 - 60	25	202	24	113
11	60 - 90	14	148	17	97
11	90 - 120	14	159	16	105
11	120 - 150	12	159	17	109
12	0 - 30	30	374	40	277
12	30 - 60	9	202	6	109
12	60 - 90	7	136	6	78
12	90 - 120	7	109	8	78
12	120 - 150	8	113	9	70
13	0 - 30	84	927	69	1248
13	30 - 60	25	409	25	550
13	60 - 90	15	241	15	304
13	90 - 120	13	159	13	222
13	120 - 150	14	148	8	140

Appendix 6. Corn yield, moisture content, stalk nitrate concentration, and Total Kjeldahl Nitrogen (TKN) data. Treatment 1 = 0 kg N ha^{-1}. Treatment 2 = 200 kg N ha^{-1}.

Site No.	Treatment	Rep	Corn yield moist (Mg ha^{-1})	Moisture (%)	Stalk NO_3-N (mg kg^{-1})	Plant TKN (%)
1	1	1	70.0	71.3	6580	1.09
1	1	2	64.9	72.3	7050	1.10
1	1	3	64.4	71.3	7730	1.24
1	1	4	65.2	72.9	8040	1.00
1	2	1	64.3	73.5	8580	1.12
1	2	2	57.7	72.1	9060	1.14
1	2	3	68.9	72.0	15350	1.08
1	2	4	66.1	72.4	8540	1.08
2	1	1	94.1	78.4	11020	1.21
2	1	2	81.6	77.3	1370	1.06
2	1	3	93.7	77.9	9920	1.14
2	1	4	80.7	78.5	7230	0.98
2	2	1	85.4	78.3	4270	1.17
2	2	2	93.2	78.5	11040	1.30
2	2	3	78.6	77.4	3660	1.10
2	2	4	76.6	77.6	10810	1.01
3	1	1	67.9	82.1	696	0.96
3	1	2	68.4	79.4	504	0.92
3	1	3	67.9	82.7	156	1.00
3	1	4	67.8	79.5	458	0.94
3	2	1	75.8	80.3	2030	1.13
3	2	2	71.1	82.1	3070	1.11
3	2	3	70.7	80.3	2120	1.04
3	2	4	72.9	82.7	1780	1.02
4	1	1	64.8	80.0	8050	1.39
4	1	2	72.2	80.2	9510	1.43
4	1	3	58.5	78.4	8320	1.32
4	1	4	61.6	79.0	7760	1.49
4	2	1	69.1	80.2	8800	1.48
4	2	2	54.0	79.4	9470	1.48
4	2	3	67.3	81.9	8650	1.56
4	2	4	54.3	78.5	7400	1.44
5	1	1	57.2	72.5	9910	1.04
5	1	2	58.1	73.1	6890	1.11
5	1	3	58.8	74.7	8900	0.98
5	1	4	63.1	72.9	11040	1.20
5	2	1	52.4	72.3	8690	1.31
5	2	2	63.3	72.5	10670	1.21
5	2	3	58.9	70.9	9580	1.06
5	2	4	67.1	74.4	12140	1.07

Appendix 6 (continued)

Site No.	Treatment	Rep	Corn yield moist (Mg ha^{-1})	Moisture (%)	Stalk NO_3-N (mg kg^{-1})	Plant TKN (%)
6	1	1	45.7	80.0	4600	1.25
6	1	2	48.4	80.6	6550	1.36
6	1	3	45.0	80.3	5110	1.13
6	1	4	44.6	78.7	5290	1.18
6	2	1	42.5	81.0	5060	1.47
6	2	2	47.3	80.8	8230	1.36
6	2	3	46.0	79.7	7070	1.30
6	2	4	45.3	79.6	6400	1.48
7	1	1	64.5	76.9	6960	1.20
7	1	2	70.5	77.3	8120	1.15
7	1	3	61.3	76.5	6100	1.09
7	1	4	66.1	76.8	9210	1.17
7	2	1	68.2	76.4	11050	1.23
7	2	2	68.1	76.1	10460	1.08
7	2	3	66.1	76.5	9130	1.27
7	2	4	67.1	75.9	9110	1.20
8	1	1	51.0	76.7	3870	1.18
8	1	2	58.0	78.3	6120	1.34
8	1	3	56.1	76.8	4850	1.28
8	1	4	61.8	77.4	3920	1.08
8	2	1	54.5	78.6	5750	missing
8	2	2	61.8	77.8	5710	1.27
8	2	3	55.8	76.6	5780	1.33
8	2	4	58.3	77.4	5390	1.28
9	1	1	69.6	79.2	7600	1.20
9	1	2	64.6	79.9	8070	1.45
9	1	3	69.4	79.3	7700	1.36
9	1	4	73.2	78.4	7500	1.24
9	2	1	59.7	81.3	8550	1.41
9	2	2	62.5	79.3	7060	1.43
9	2	3	66.0	79.5	7600	1.32
9	2	4	70.5	78.4	8850	1.24
10	1	1	68.9	77.8	11590	1.54
10	1	2	62.1	78.3	12650	1.44
10	1	3	64.6	77.5	13080	1.41
10	1	4	69.0	78.6	13070	1.53
10	2	1	75.5	77.7	11360	1.45
10	2	2	71.5	78.0	13700	1.46
10	2	3	79.2	78.0	13890	1.46
10	2	4	72.5	78.7	11300	1.42

Appendix 6 (continued)

Site No.	Treatment	Rep	Corn yield moist (Mg ha^{-1})	Moisture (%)	Stalk NO_3-N (mg kg^{-1})	Plant TKN (%)
11	1	1	68.9	80.7	8220	1.42
11	1	2	71.8	81.0	7330	1.41
11	1	3	72.0	80.4	6550	1.40
11	1	4	65.4	79.7	6970	1.45
11	2	1	78.1	80.9	8650	1.43
11	2	2	69.2	81.1	8740	1.58
11	2	3	73.6	80.9	missing	1.58
11	2	4	67.5	80.9	8320	1.60
12	1	1	60.3	81.4	153	0.84
12	1	2	50.6	83.1	1220	0.88
12	1	3	54.2	82.0	24	0.85
12	1	4	66.0	82.5	458	0.95
12	2	1	58.5	81.6	2890	1.21
12	2	2	73.5	80.9	2670	1.06
12	2	3	65.0	81.7	3300	1.11
12	2	4	60.4	82.3	2850	1.09
13	1	1	60.2	83.0	11250	1.72
13	1	2	66.2	81.8	10210	1.80
13	1	3	59.8	82.5	missing	1.61
13	1	4	59.4	80.6	9460	1.77
13	2	1	66.8	83.2	11580	1.93
13	2	2	61.6	81.3	9840	1.48
13	2	3	65.9	81.3	9650	1.50
13	2	4	62.7	82.0	12210	1.69
14	1	1	66.5	73.1	4509	1.18
14	1	2	61.8	73.5	7415	1.28
14	1	3	66.5	72.4	4537	1.13
14	1	4	63.5	73.1	4537	1.19
14	2	1	74.6	75.1	7025	1.30
14	2	2	70.1	74.1	6180	1.19
14	2	3	71.2	76.3	6440	1.39
14	2	4	70.0	73.7	6060	1.30
15	1	1	35.7	70.9	4073	1.18
15	1	2	36.1	73.5	1491	1.02
15	1	3	31.2	72.6	1854	1.14
15	1	4	24.4	73.1	4611	1.30
15	2	1	38.1	72.1	2931	1.32
15	2	2	30.1	73.4	4147	1.31
15	2	3	38.0	73.7	6199	1.37
15	2	4	34.1	74.4	5707	1.39

Appendix 6 (continued)

Site No.	Treatment	Rep	Corn yield moist (Mg ha^{-1})	Moisture (%)	Stalk NO_3-N (mg kg^{-1})	Plant TKN (%)
16	1	1	54.0	75.7	10396	1.33
16	1	2	60.7	77.1	13024	1.44
16	1	3	57.4	76.3	13042	1.30
16	1	4	55.3	75.7	10034	1.46
16	2	1	56.0	77.2	12197	1.52
16	2	2	53.3	76.3	11269	1.32
16	2	3	54.2	75.8	15661	1.49
16	2	4	57.8	75.4	13804	1.45
17	1	1	43.4	78.4	10619	1.44
17	1	2	47.0	76.3	4998	1.32
17	1	3	42.0	75.9	8307	1.39
17	1	4	47.1	77.0	5029	1.32
17	2	1	40.8	77.9	5347	1.38
17	2	2	40.1	77.9	5308	1.42
17	2	3	49.3	75.6	7833	1.37
17	2	4	47.4	77.2	5354	1.46
18	1	1	70.6	73.3	9066	1.07
18	1	2	61.3	75.3	9236	1.18
18	1	3	64.8	74.7	7433	1.16
18	1	4	72.5	73.1	7641	1.16
18	2	1	71.3	72.0	8924	1.06
18	2	2	75.0	73.8	11416	1.13
18	2	3	72.1	73.6	8122	1.28
18	2	4	73.9	73.6	12615	1.28
19	1	1	64.4	70.3	9594	1.29
19	1	2	60.4	74.2	12983	1.24
19	1	3	60.0	73.5	9906	1.33
19	1	4	58.9	71.7	8207	1.27
19	2	1	61.5	72.6	13115	1.45
19	2	2	53.6	72.8	12237	1.43
19	2	3	55.1	74.7	11746	1.47
19	2	4	55.7	72.7	14361	1.32
20	1	1	84.4	74.2	9019	1.20
20	1	2	76.9	77.4	6055	1.19
20	1	3	92.9	77.0	12284	1.23
20	1	4	94.3	76.9	12388	1.15
20	2	1	86.4	78.5	16192	1.40
20	2	2	87.7	78.1	17985	1.31
20	2	3	99.6	76.7	12907	1.26
20	2	4	90.4	77.5	18334	1.40

Appendix 6 (continued)

Site No.	Treatment	Rep	Corn yield moist (Mg ha^{-1})	Moisture (%)	Stalk NO_3-N (mg kg^{-1})	Plant TKN (%)
21	1	1	69.1	73.3	279	0.89
21	1	2	74.3	71.6	65	0.82
21	1	3	69.1	73.8	534	0.88
21	1	4	73.0	73.5	1884	1.07
21	2	1	80.3	73.7	2056	1.15
21	2	2	81.7	74.5	3330	1.13
21	2	3	77.8	74.6	2403	1.05
21	2	4	89.3	74.7	4403	1.12
22	1	1	59.2	75.9	4481	1.19
22	1	2	72.8	77.0	3736	1.20
22	1	3	72.3	73.9	6302	1.24
22	1	4	65.7	73.3	3292	1.12
22	2	1	68.4	76.2	6783	1.21
22	2	2	72.1	76.5	6717	1.15
22	2	3	66.3	76.2	5755	1.34
22	2	4	69.6	76.4	3113	1.28
23	1	1	78.5	75.5	8435	1.22
23	1	2	86.9	73.1	6453	1.06
23	1	3	83.4	75.9	9171	1.18
23	1	4	84.8	74.3	6321	1.06
23	2	1	81.3	75.0	9973	1.17
23	2	2	82.1	75.7	8237	1.48
23	2	3	94.4	74.5	8501	1.27
23	2	4	95.1	77.3	11284	1.24
24	1	1	69.8	73.9	13926	1.44
24	1	2	67.1	75.8	14341	1.49
24	1	3	65.1	75.5	15360	1.55
24	1	4	67.6	74.8	15049	1.42
24	2	1	65.5	78.0	13020	1.56
24	2	2	73.4	76.6	15813	1.41
24	2	3	72.1	73.8	13209	1.45
24	2	4	59.7	77.5	13766	1.52
25	1	1	73.2	84.7	14511	1.78
25	1	2	83.3	80.9	10473	1.46
25	1	3	69.5	84.1	14219	1.79
25	1	4	81.7	81.2	12435	1.46
25	2	1	72.0	84.2	17974	1.94
25	2	2	81.6	84.1	15964	1.59
25	2	3	73.0	83.5	16908	1.73
25	2	4	79.8	83.4	17002	1.63

Appendix 6 (continued)

Site No.	Treatment	Rep	Corn yield moist (Mg ha^{-1})	Moisture (%)	Stalk NO_3-N (mg kg^{-1})	Plant TKN (%)
26	1	1	84.4	83.8	17455	1.76
26	1	2	72.8	82.6	15907	1.67
26	1	3	78.6	83.5	15879	1.65
26	1	4	79.9	83.9	14483	1.60
26	2	1	85.5	83.6	15530	1.68
26	2	2	73.6	81.9	14294	1.68
26	2	3	82.0	84.2	18200	1.76
26	2	4	77.5	82.6	13615	1.49